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## THE NEW BROADCASTING TRANSMITTERS IN THE NETHERLANDS

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621.396.712

Two new broadcasting transmitters of 125 kW have recently been constructed to replace the Netherlands broadcasting transmitters in Hilversum and Jaarsveld. Both the new transmitters are housed in the same building. This article gives a general account of the installation.

At the beginning of this year the Netherlands broadcasting transmitters of Hilversum and Jaarsveld were replaced by a single central installation, which is so situated that it gives optimum reception throughout the whole of the Netherlands. This new installation, supplied by Philips, consists of two transmitters, each of 125 kW, which work on 336 m and 415 m, respectively. The wave length of 336 m was assigned to the Netherlands by the Montreux plan; at present this plan is not in operation, and therefore the transmitter in question is temporarily tuned to a wave length of 301.5 m.

In designing the new transmitters special attention was paid to the efficiency, in connection with the high power to be radiated. The necessity of achieving high efficiency led to connections with which the transmission energy is supplied to the aerial through four almost identical channels, each consisting of three successive stages. Compared with normal connections, in which the modulated high-frequency energy is amplified in a series of successive stages to the desired level, an economy of more than 250 kW has been obtained in this way.

It is not the intention of this article to describe the action of the connections with four channels, or to go into the way in which the improvement in the efficiency is achieved. This will be dealt with in a future article in this periodical. In this article, however, we shall discuss the influence which the splitting of the transmitter connections into four channels has had on the design of the whole installation, after which several particulars of the construction will be considered.

### The general plan

The most obvious plan for an installation on the

principle mentioned is represented in fig. 1, where the fanshaped design meets the necessity of larger dimensions for each successive stage. As may be seen the splitting of the system into four channels does not take place immediately, but in two steps, upon transition from the second to the third stage and from the third to the fourth stage. The fourth stage is controlled by the modulator, and each of the channels is affected in a different way. The resulting unequal division of the transmission energy

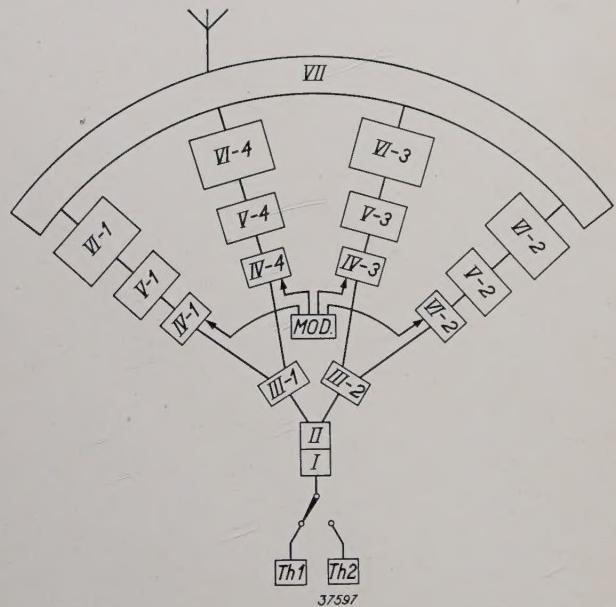


Fig. 1. Scheme of the new Netherlands broadcasting transmitters, represented in a form which could be considered as a ground plan. The high-frequency energy is amplified in six stages (I-IV), of which stage III is split into two channels and stages IV, V and VI into four channels. VII is a network which couples the four output stages with each other in a certain way, and transmits the energy provided to the aerial. MOD is a modulator acting on stage IV which regulates the amplitude of the high-frequency signal in the four channels, in a special way for each channel. Th 1 and Th 2 thermostats with quartz crystals for keeping the frequency constant.

is the means by which the high efficiency is attained.

The fan-shaped design has in principle the advantage that the four channels could with little difficulty be built so that they may be considered mutually identical, which is desirable in order to prevent relative phase shifts between the high-frequency signals of the four channels. Such phase shifts are not permissible if the satisfactory functioning of the whole unit is at stake. Practically, however, this design is less satisfactory and was finally abandoned since the operation as well as the control become fairly difficult.

Ease in operation and control requires as compact as possible an arrangement, which can be realized for the first four stages, together with the modulator, in the manner shown in fig. 2a. The sixth stage, which, like the fourth and fifth, consists of four channels, requires more space, and it was therefore set up separately (see fig. 2b). The coupling of stage IV with stage V and of stage V with stage VI is by means of connection lines which are of exactly the same length for the different channels. The identity of the four stages as to the phase of the high-frequency signal, is sufficiently well guaranteed by this means.

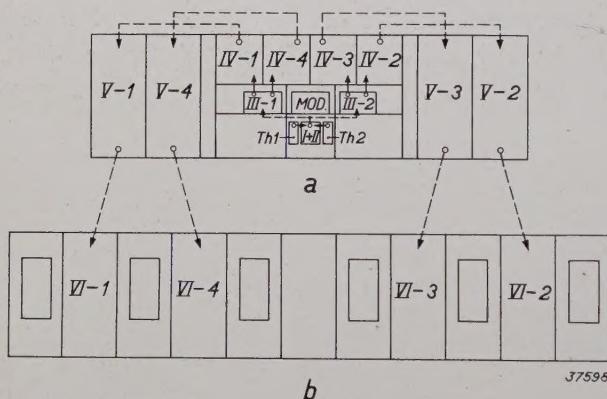


Fig. 2. Diagrammatic front view of the transmitter as installed.

The relative arrangement of the parts of the transmitter *a* and *b* corresponds exactly to the sketch just discussed. This is not to be considered as a ground plane, but as a vertical cross section, *i.e.* the preliminary stages *a* are situated on a gallery above the final stage *b*. The whole transmitter is set up against one wall of a large hall; along the opposite wall is the second transmitter, which corresponds exactly to the first except for its wavelength.

Fig. 3 represents a transverse cross section through the middle of the transmitter building, which consists in the main of two storeys, on the ground floor the machine hall (*I*) and above it the

transmitter hall (*II*). In the machine hall are the different feed sources of the installation: for low voltages and heavy currents converters are installed, while the high voltage of the final stage is obtained with the help of a transformer and rectifier. On the galleries of the machine hall stand the insulation spirals which provide the necessary length of path for the cooling water to prevent the high potential of the anodes of the output valves being conducted away to earth by way of the cooling water.

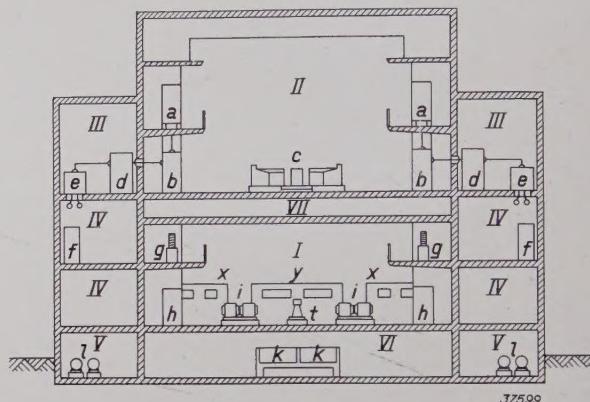


Fig. 3. Vertical cross section through the transmitter building.

<i>I</i> Machine hall	<i>d</i> anode circuits of output stage
<i>II</i> and <i>III</i> Transmitter hall	<i>e</i> aerial coupling circuit and filters
<i>IV</i> Workshop, etc.	<i>f</i> artificial aerials
<i>V</i> Pump cellar	<i>g</i> cooling-water spirals
<i>VI</i> Cable cellar	<i>h</i> switch board machine room
<i>VII</i> Cable space	<i>i</i> converters
<i>a</i> preliminary stages	<i>x, y</i> 20 kV rectifiers
<i>b</i> output stage	
<i>c</i> operation desk	

Fig. 4 is a ground plan of the machine hall. *x* and *y* are rectifiers for the high voltage of the final stages; the transformers *v* and *w*, respectively, belong to these rectifiers. Each of the two rectifiers *x* serves for the supply of one transmitter, while *y* forms the common reserve. The converters for the low voltages are indicated by *i*. Three heating-current dynamos are used, namely, of 15, 25 and 35 volts, respectively, for 50, 320 and 830 amp., in order not to be compelled to dissipate too much energy in series resistances for the filaments of lower voltage by the use of one dynamo of 35 volts. Furthermore a double dynamo for 2 000 volts, 2 amp. and 450 volts, 1 amp. furnishes the anode voltages and screen-grid voltages of various preliminary stages, while two double dynamos, each for 400 volts, 2.5 amp. give the grid bias voltages for the four channels of the final stage. Finally there is a dynamo for 110 volts, 18 amp. for the excitation of the other machines. The motive energy for the dynamos is taken from the local high-voltage mains with the help of the transformers *r*, which are built into

separate cells at the end of the machine hall. Here also one transformer serves each transmitter normally, while a third transformer is in reserve.

For the further arrangement of the machine hall we refer to the text under fig. 4. Finally in fig. 5 two photographs of the machine hall are reproduced: in one photograph may be seen the middle rectifier (*y* in fig. 4) behind a set of converters, while the other shows the switch board for the feed voltages (*h* in fig. 4).

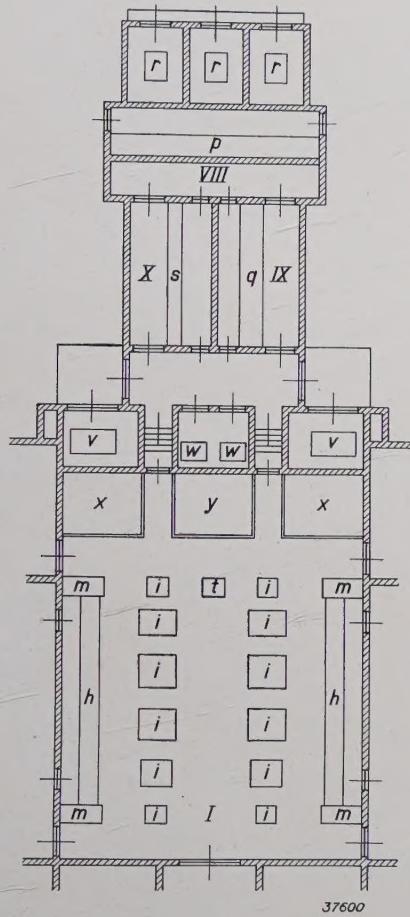


Fig. 4. Ground plan of the machine hall

I Machine hall                    m cable channels  
 VIII Cable switch room        r mains transformers  
 IX High-voltage switchroom, w    transformers for 20 kV  
 X Low-voltage switch room      rectifiers

As already mentioned, the transmitters proper are in the hall above the machine hall. The plan is given in fig. 6. The different components of the transmitter are indicated in the same way as in fig. 3, so that the sketch is clear without much explanation. At the front are two rooms, one for the head of works (*XI*) and one for an amplifier room (*XII*), with a view through broad windows into the transmitter hall. In the amplifier room the microphone amplifiers are situated on a rack (*O*). Along the side walls of the hall are the final stages (*b*) of the four channels; above on the galleries, not

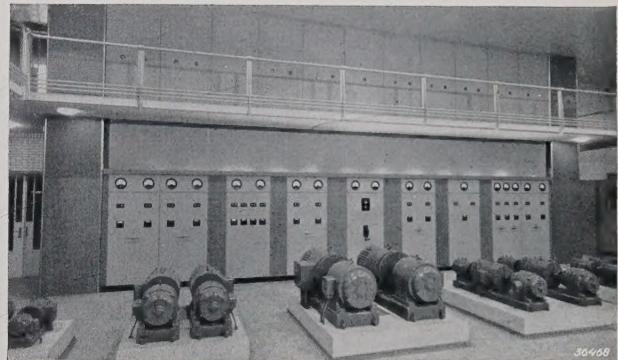
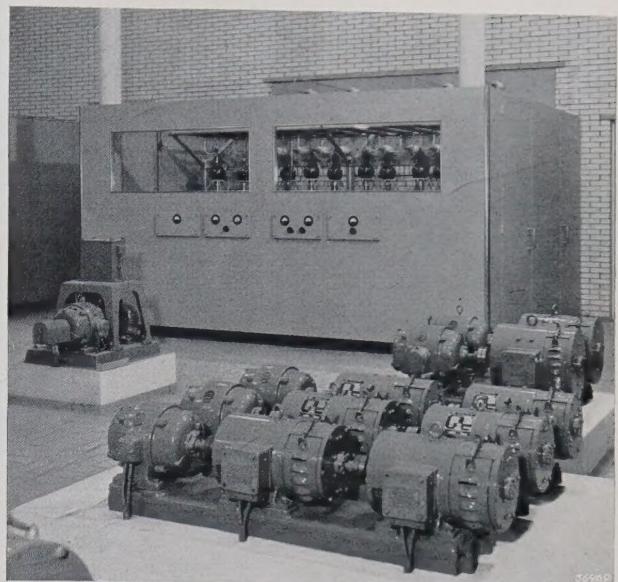


Fig. 5. Machine hall. Upper photograph, the 20 kV rectifier behind a set of converters; lower photograph, the switch board belonging to the converters.

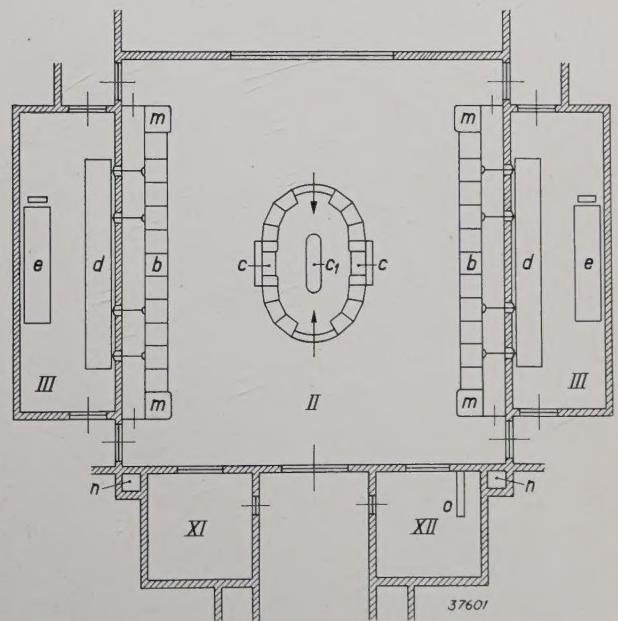


Fig. 6. Ground plan of the transmitter hall and the adjacent rooms. For the meaning of the letters and numbers see fig. 3  
 XI room for the works manager, XII amplifier room with amplifier rack *O*.

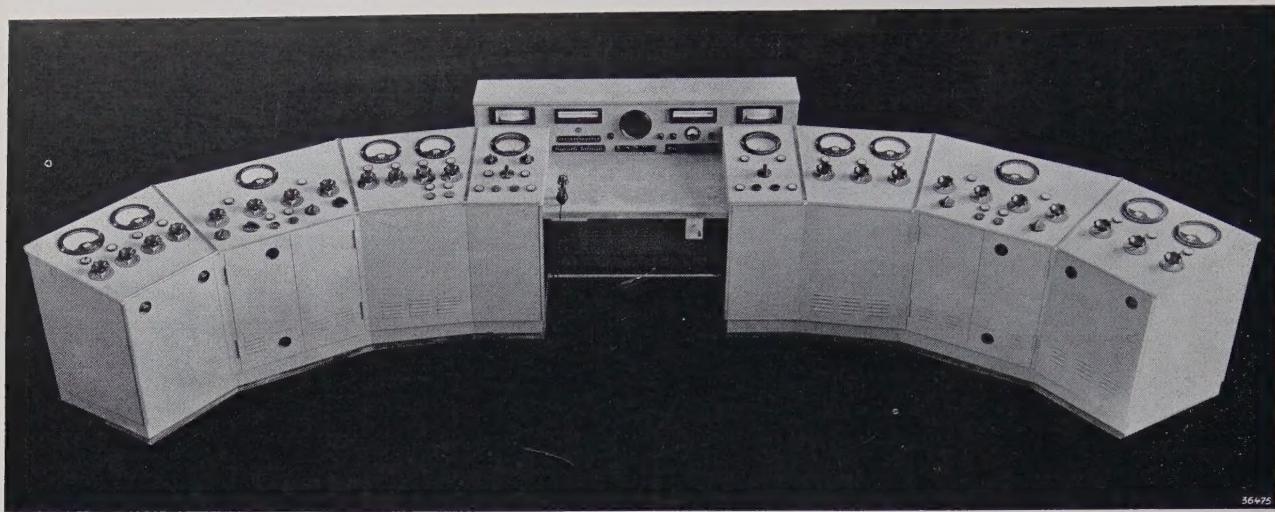


Fig. 7. Supervising and operating desk.

given in the floor plan, are the preliminary stages. The cables and cooling-water lines to these preliminary stages run through the cable channels (*m*) which may be seen on either side of the final stages. In the side rooms *III* of the transmitter hall is the

anode network *d* of the final stage, which couples the four channels with each other, and also a cabinet *e* with the coupling circuit which transmits the output energy of the transmitter, after the higher harmonics have been filtered out, to the aerial. In

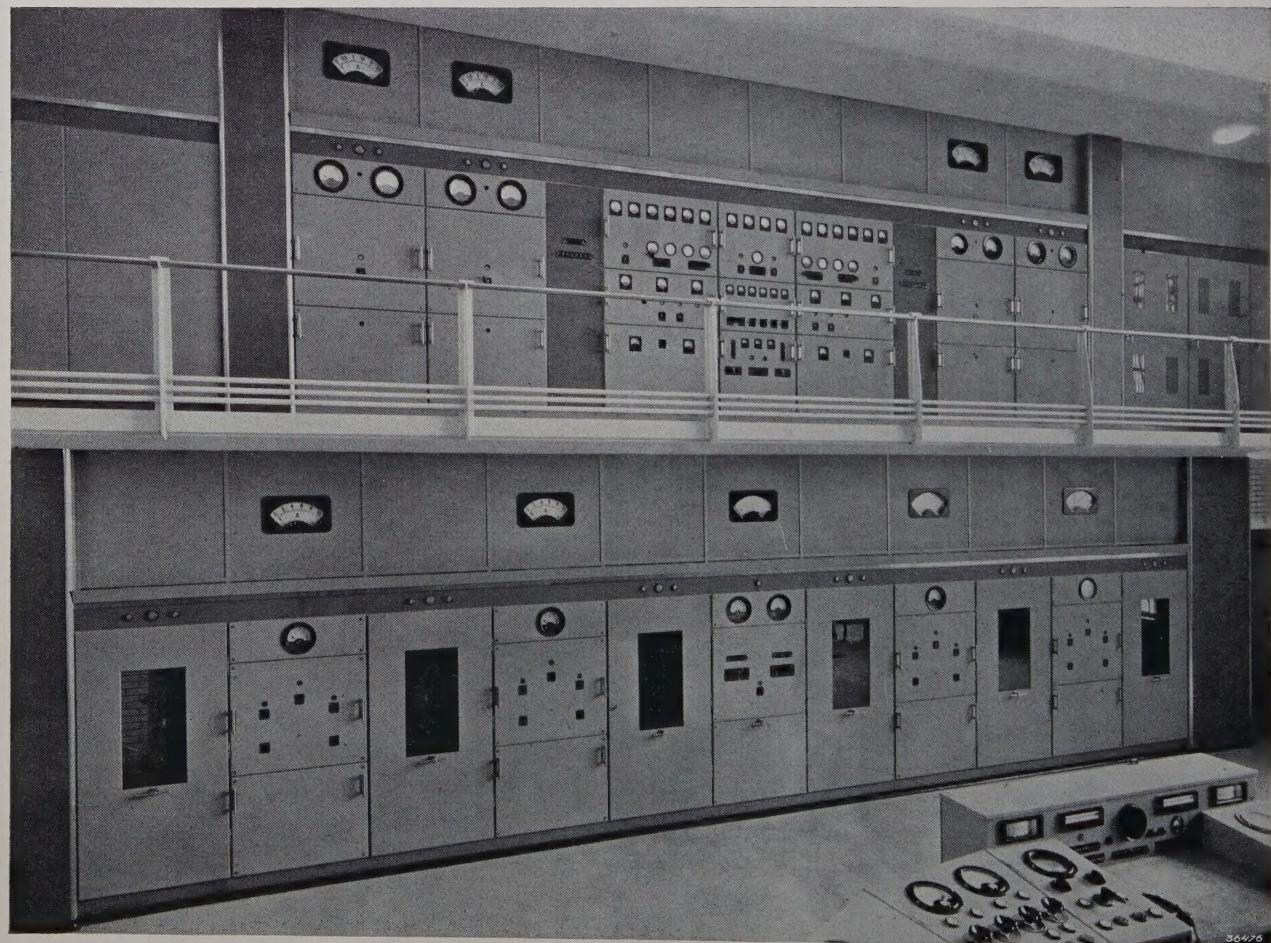


Fig. 8. Front of the transmitter seen from the operating desk. On the gallery the preliminary stages *I-V*; below the output stage *VI*. The sub-division of the front panel follows from the diagram of fig. 2.

the middle of the hall is the operating desk, half of which (for one transmitter) is shown in fig. 7. All the manipulations necessary for operating both transmitters can be carried out from this desk, with the exception of the switching in and over of

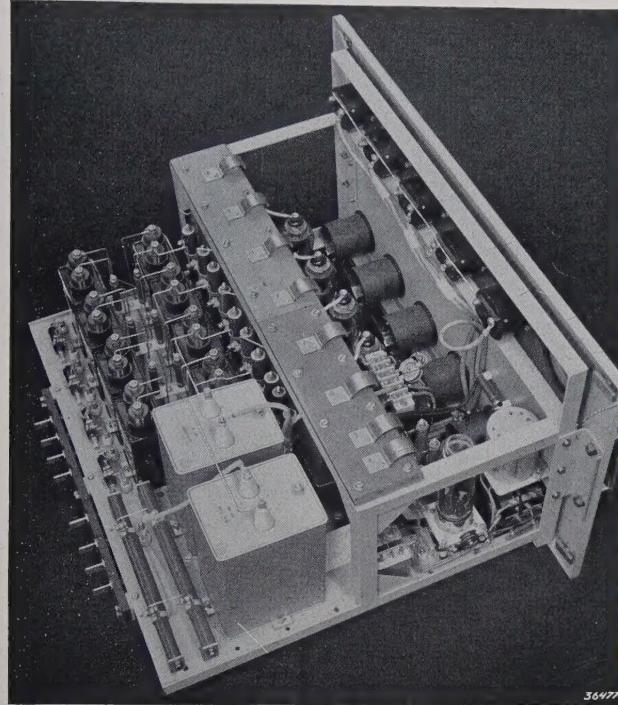


Fig. 9. Sliding chassis containing the modulator stage. To the left may be seen the knife contacts which serve for the electrical connections when the chassis is in position.

the machines, which takes place in the machine hall itself, with simultaneous control by means of the measuring instruments present there. In fig. 8 the panel of the whole transmitter has been photographed from the desk to show how, thanks to the arrangement in two storeys and the generous dimensions of the instruments, a good view of the whole installation is obtained. It is also striking that no operating knobs occur anywhere on the transmitter panel. This has been expressly avoided in order to prevent disadjustment of the transmitter, for instance by careless visitors. All the operating shafts can be moved by the personnel with the help of a removable handle.

#### Several structural details of the transmitter

In the construction of the transmitter, spaciousness has been aimed at, in order that all components should be easily accessible. This is particularly important for those components which must be able to be exchanged, such as valves and fuses.

In order to facilitate access to the components the front panels of the transmitter are fastened with

toggles and provided with handles, and all the valves are set up behind doors. Smaller components are mounted in sliding chassis (see fig. 9) with the employment of knife contacts for the passage of the current.

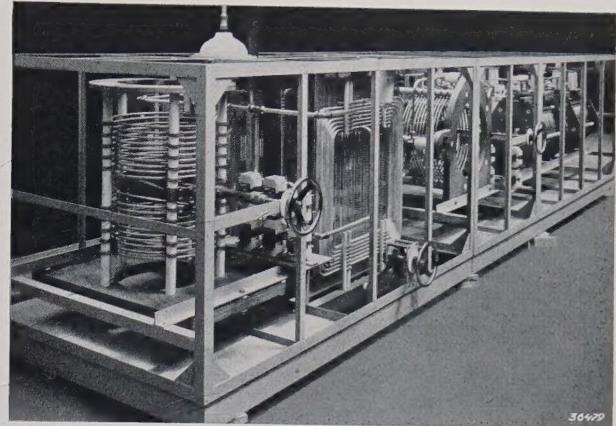


Fig. 10. Coupling circuit which transmits the energy from the output stage to the aerial. Also filters for eliminating the higher harmonics from the aerial signal.

A further discussion of the electrical construction of the transmitter lies outside the scope of this article. In order, however, to give some idea of the mechanical construction of the electrical components, three photographs of characteristic compo-



Fig. 11. Tuning circuits for the output stage of the transmitter. Below the astatically arranged coils may be seen the tuning condensers which are operated by motors.

nents are given in figs. 10, 11 and 12. We wish to call special attention to the construction of the coils of the high-frequency output stages in fig. 11. These coils are subdivided into two astatic halves, so that the mutual coupling of the coils is kept extremely small without external shielding.

Two self-radiating masts of 192 m and 165 m, respectively serve as aerials for the transmission waves of 415 m and 356 m. The earth connections network consists of 108 copper wires of 200 m and 180 m length, respectively, buried in the ground in ray arrangement between an inner and an outer ring.

#### Tuning of the transmitter

Except in the final stage, the circuits of the transmitter can be tuned in quite the ordinary way, since the preliminary stages of the different channels are independent of each other. Since, however, the channels of the final stage act on a common anode circuit, special measures had to be taken for the tuning of the final stage. The network which couples



Fig. 13. Measuring wagon with cathode ray oscillosograph for supervising the relative phases of the voltages in the four channels.

the anode circuits of the output valves with each other is such that the anode circuit of one channel can most easily be tuned when the anode circuits of the adjacent channels are short circuited. The short circuiting is accomplished with the help of mechanical switches. These switches are operated with servo motors from the front of the transmitter, like the tuning condensers of the different channels. The anode voltage of the valves with short-circuited anode circuit can be disconnected by switches. These switches are electrically locked to the corresponding short-circuit switches, so that it is impossible to switch on the anode voltage of valves with a short-circuited anode circuit.

When in this way one channel is separated from the rest the oscillation circuits can be tuned, and by the adjustment of certain bias voltages in the modulation stage the carrier wave can be influenced in the desired way by the modulation voltage. As already stated, the nature of this influence is different for each channel; it is best to judge the relation between the modulation voltage and the amplitude of the output signal experimentally with the help of four cathode ray tubes which are built into the panel of the transmitter.

For satisfactory performance of the transmitter, not only are the amplitudes of the signals in the four channels important, but also the relative phases. In order to avoid phase shifts it is necessary to

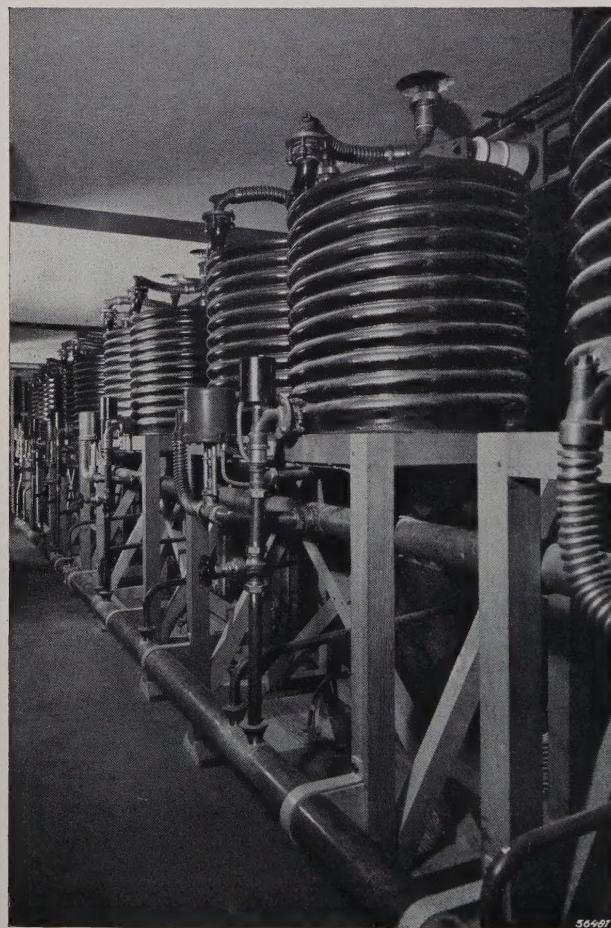


Fig. 12. Insulation spirals through which flows the cooling water for the anodes of the output valves. The water from six valves (four channels and two reserve valves) must pass through an insulation spiral both coming and going, so that 12 such spirals are needed. They are made entirely of porcelain and have a capacity of 120 litres of cooling-water per minute.

compensate exactly the grid-anode capacities of the triodes TA 18/100 used in the output stage, which vary slightly for different valves of that type. The neutrodyne condensers used for that purpose are constructed in two parts, the main part of which is adjusted once, while the correction part can be regulated from the front panel of the transmitter. The regulation can best be accomplished by checking the correctness of the relative phases of the four channels by means of a cathode ray oscilloscope. For this purpose a transportable apparatus in the form of a measuring wagon is used. This is shown in fig. 13.

In fig. 14 may be seen the rack and pinion drive by which the correction part of the neutrodyne capacity is adjusted; this picture is also characteristic of the way in which the tunable components housed in closed compartments are operated by means of sliding switches. The neutrodyning must be repeated every time a transmitter valve is replaced by a new one. In order to facilitate this a spare valve is built in for each two channels, which is previously neutrodyed with the help of

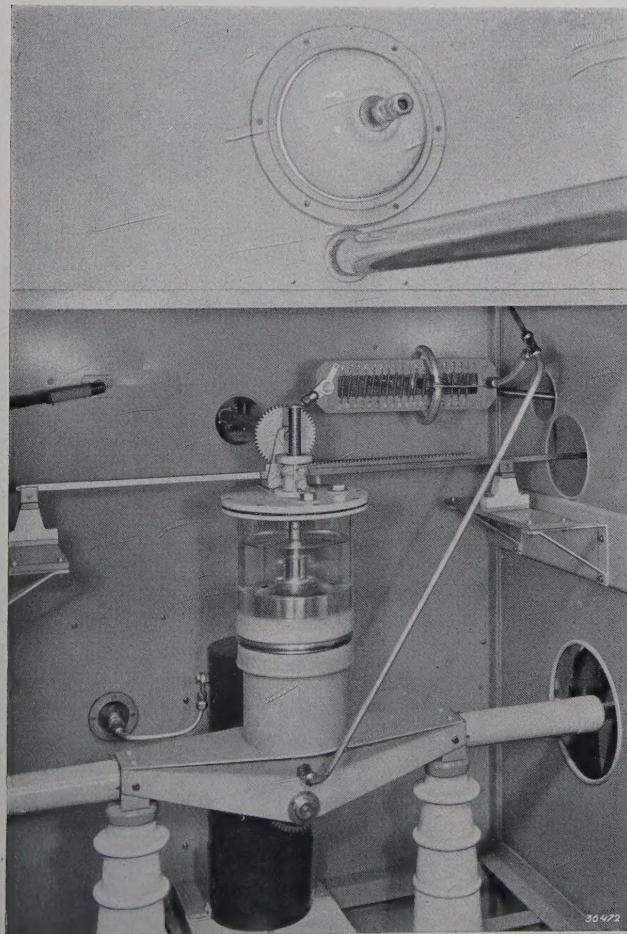


Fig. 14. Neutrodyne condenser which is set by means of a rack and pinion.

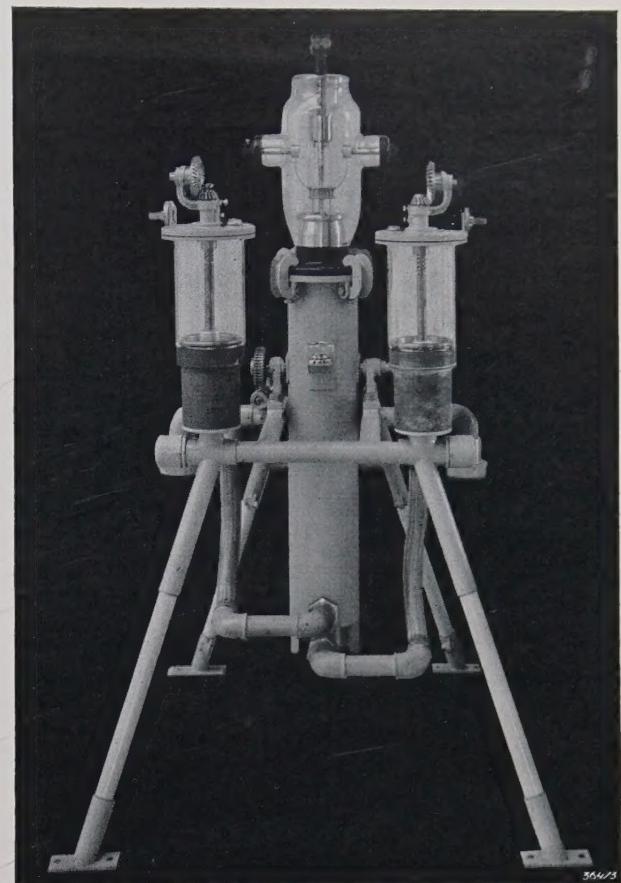


Fig. 15. Spare valve with two neutrodyne condensers, which are adjusted for the two channels, respectively, in which the valve there present might have to be replaced.

two neutrodyne condensers for each of the two channels (see fig. 15). Switching over to a spare valve therefore only requires a minimum time (about 15 sec) and can be done by unskilled personnel.

#### Characteristics of the transmitter

Compared with the ordinary transmitter connections, the installation described, in which the

Distortion of low-frequency signals at a modulation depth of 90%		Efficiency at different depths of modulation		
frequency c/s	distortion		efficiency output stage	efficiency of whole trans- mitter
300	3.2%	carrier-wave without mod.	58.9%	36%
400	3.0%			
2 000	3.9%	30% mod.	56%	35%
6 000	5.5%			
9 000	6.3%	100% mod.	55%	38%

modulation is distributed over four channels, offers the advantage of a considerably higher efficiency. The degree of efficiency depends upon the way in which this division is carried out. The higher the desired efficiency, the greater the distortions which must in general be tolerated; the final result may thus be considered as a compromise between the efficiency of the transmitter and the fidelity of the reproduction. In the case of the transmitter as adjusted for the acceptance examination the values for efficiency and distortion given in the above table were measured.

If, in agreement with practical experience, it is assumed that with the ordinary construction of the transmitter an efficiency of only about 20 per cent would have been attained, the present construction represents an economy of more than 250 kW. This economy is particularly important because it not only means an economy in the current consumption, but at the same time it has a favourable effect on the dimensions of the water-cooling system and other components which must dissipate the heat developed without harmful rise in temperature.

## NEW KINDS OF STEEL OF HIGH MAGNETIC POWER

by B. JONAS and H. J. MEERKAMP van EMBDEN.

669.15.018.58

By exposing steel for permanent magnets to a magnetic field during the heat treatment (magnetic hardening), considerable improvement in the magnetic qualities can be attained in certain cases. The maximum product of induction and internal field strength (magnetic power), which determines the quality of a magnet steel, could in this way be increased from  $2.2 \times 10^6$  to  $5.2 \times 10^6$  gauss-oersted in the case of the magnet steel alloy "Ticonal".

The significance of this progress is briefly explained in this article.

Although certain general ideas already exist about the magnetic properties of alloys, in working out the most favourable composition of an alloy of which certain magnetic properties are required, experience is still almost the only guide. This is true also for the alloys for permanent magnets which have been developed in the Philips Laboratory chiefly for use in electrodynamic loud speakers.

Although the starting point of these investigations was the carbon-cobalt type of steel then used for that purpose, after the discovery of Mishima in 1932 that better and cheaper permanent magnets could be made from iron alloys with nickel and aluminium in certain proportions, magnet steels were developed which contained these latter elements as well as titanium and cobalt<sup>1)</sup>.

In the research on these new kinds of steel, which were sold under the name "Ticonal", not only was the composition varied in many ways, but also the nature of the heat treatment. The results were judged in each case by recording the magnetization curve and especially the remanence  $B_r$  and the

coercive force  $H_c$  (see fig. 1). It was found that coercive forces of more than 1 000 oersted could be obtained. The remanence is usually found to decrease with increasing coercive force, so that the product of coercive force and remanence, which to a certain point may be considered as a measure of the magnetic power of the steel, cannot be increased above a certain limit of about  $6 \times 10^6$  gauss-oersted.

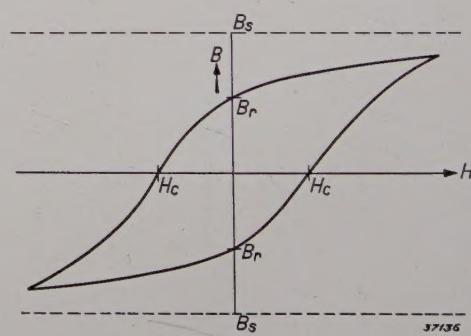


Fig. 1. Hysteresis loop of a magnet steel.  $B_r$  remanence,  $H_c$  coercive force.

Actually the quality of a magnet steel cannot be determined exactly by the product of remanence and coercive force, but by the maximum value  $(BH)_{\max}$  of the product of induction and internal field strength, which may occur when the material

<sup>1)</sup> On the fundamental difference between the magnetic hardening phenomenon in the case of these alloys and that of the earlier known kinds of magnet steel see J. L. Snoek, Philips techn. Rev. 2, 233, 1937.

is placed in a demagnetizing field<sup>2)</sup>). If  $B_r H_c$  has a value of  $6 \times 10^6$  gauss-oersted,  $(BH)_{\max}$  has a value of approx.  $2 \cdot 10^6$  gauss-oersted. The quotient  $(BH)_{\max} : B_r H_c$  is indicated by the term convexity factor. For an exactly rectangular demagnetization curve (fig. 2a) the convexity factor would be equal to 1; for a straight line (fig. 2b) one finds 0.25. The

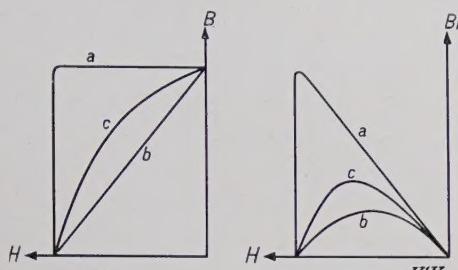


Fig. 2. *a* and *b*: Limiting cases of demagnetization curves, *c*: technical magnetization curve. Left-hand diagram *B* as a function of *H*; right-hand diagram *BH* as a function of *H*. The "convexity factor"  $(BH)_{\max} : B_r H_c$  may vary between 1 and 0.25 (curve *a* and *b*, respectively); in the case of the technical curve given *c* it has a value of 0.4.

actual magnitude of the convexity factor usually lies between these two extreme values, and for the "Ticonal" type of steels it has a value of about 0.4.

On the basis of extensive attempts to reach the best possible results by variation of the composition and treatment of the alloys in question, it appeared as if the value of  $(BH)_{\max}$  could not in

<sup>2)</sup> See A. Th. van Urk, Philips techn. Rev. **5**, 29, 1940.

practice be raised above  $2.2 \times 10^6$  gauss-oersted. In 1938, however, in the Philips Laboratory this value was suddenly considerably exceeded by subjecting certain new magnet steel alloys<sup>3)</sup> to a heat treatment in a magnetic field and then annealing them in the usual way<sup>4)</sup>. It was found possible in this way to increase  $(BH)_{\max}$  to the unequalled value of  $5.2 \times 10^6$  gauss-oersted, so that it may be stated that the quality of the steel has improved by a factor of more than 2.<sup>5)</sup>

A large part of this improvement may be ascribed to an increase in the convexity factor. As may be seen in fig. 3 the demagnetization curve of the new kinds of steel takes on a more or less rectangular shape as a result of the magnetic treatment, which means that the convexity factor begins to approach 1. The highest convexity factor measured for magnetically hardened types of steels is 0.76, and

<sup>3)</sup> The alloys contain the same metal as the "Ticonal" steels previously developed, but in different proportions. A special requirement is a relatively high content of cobalt, which, in connection with the high price of this metal, at first seemed to be a disadvantage.

<sup>4)</sup> The application of a magnetic field during this annealing was found to be quite superfluous.

<sup>5)</sup> A preliminary statement on this subject was made by G. Holst before the Ned. Natuur- en Geneesk. Congress, April 11th 1939; see de Ingenieur **54**, A 199, 1939. From an article by D. A. Oliver and J. W. Shedd, Nature London **30**, 7, 1938, it appears that these investigators have carried out tests of the action of a magnetic field during the heat treatment of a so-called "Alnico" steel. Only a small increase in the remanence and the value of  $(BH)_{\max}$  was observed.

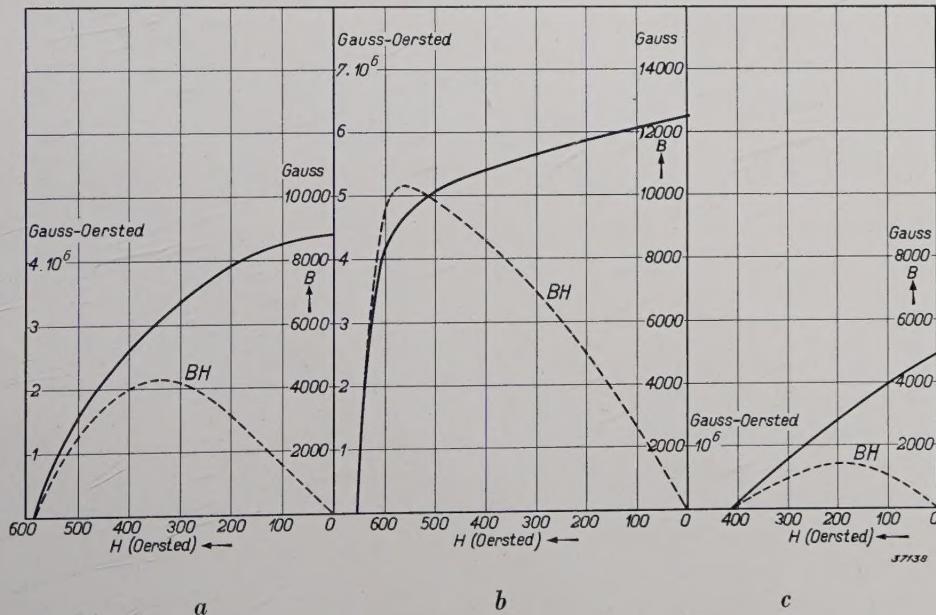


Fig. 3. Demagnetization curve of a magnet steel, consisting of 51.5% iron, 8.5% aluminium, 14% nickel, 23% cobalt and 3% copper. *a*) Optimum heat treatment without magnetic field, *b*) heat treatment in a magnetic field with the direction in which the *B-H* curve is measured. In this case a value of  $(BH)_{\max}$  of  $5.2 \times 10^6$  gauss-oersted is obtained. *c*) The same steel as curve *b*), measured in a direction perpendicular to that of the magnetic field applied during the heat treatment. Full lines, *B* as function of *H*, broken lines, *BH* as a function of *H*.

therefore nearly twice as large as that which occurs for the same types of steel without magnetic treatment.

The remarkable character of the  $B$ - $H$  curve may be explained by assuming that the elementary magnets possess a preferred orientation in the direction of the magnetic field applied during the heat treatment. In agreement with this explanation is the fact that a pronouncedly flat demagnetization curve is measured in the direction perpendicular to the field applied during the heat treatment, as is shown in fig. 3c. The convexity factor for this direction of magnetization only has a value of 0.32, while the convexity factor in the direction of the preferred orientation amounts to 0.66.

When curves 3b and 3c are compared with the curves drawn in fig. 3a for the same material upon heat treatment without a magnetic field (convexity factor 0.43), it is seen that the field applied during the heat treatment (of about 3000 oersted) considerably increases  $B_r$  and  $H_c$  and particularly  $(BH)_{\max}$  in the direction parallel to it, while in the direction perpendicular to the field all three quantities are considerably decreased.

Since the beginning of 1939 the new method has been employed in manufacture on a large scale. The necessary magnetic field is generated with permanent magnets, a fact which has been made possible by the use of the new kinds of magnet steel themselves. The product on the market under the name "Ticonal" 3.8 possesses a value of  $(BH)_{\max}$  of 3.8 to  $4 \times 10^6$  gauss-oersted. At the same time a remanence of more than 12 000 gauss is reached. For the sake of comparison it may be mentioned that the platinum-cobalt steel which, because of its expensiveness, could not be used for technical purposes, and which, before the development of the magnetically hardened steel, was the best magnet steel known, possessed a  $(BH)_{\max}$  value of  $3.4 \times 10^6$  gauss-oersted with a remanence of only 4 000 gauss.

The results of the introduction of the new kinds of magnet steel into technology can as yet hardly be realized. It is, however, clear that not only as to new technical possibilities<sup>6)</sup>, but also as to the price of the new magnet steel products, the prospects are very favourable. In technical respects to high remanence is a good quality in addition to the high  $(BH)_{\max}$  value. The high remanence makes possible constructions which exhibit a relatively small spreading of the magnetic

flux, so that full advantage can be taken of the high magnetic energy per unit volume of the steel for the effective field in the air gap of the apparatus to be constructed. Since by this means a given technical problem can be solved with an unusually small amount of magnet steel, the cost price of the new magnet steel products is quite favourable. Some of the raw materials, such as cobalt and nickel, are indeed fairly expensive. If, however, the price of magnetically hardened "Ticonal" steel is calculated per unit of magnetic energy, it is found that, thanks to the high magnetic energy per unit volume, the price is lower than that of any other kind of magnet steel which has been developed in the last 20 years. Summarizing, we may therefore conclude that the new kind of steel is certainly predestined to replace in many cases the types of magnet steel used until now.

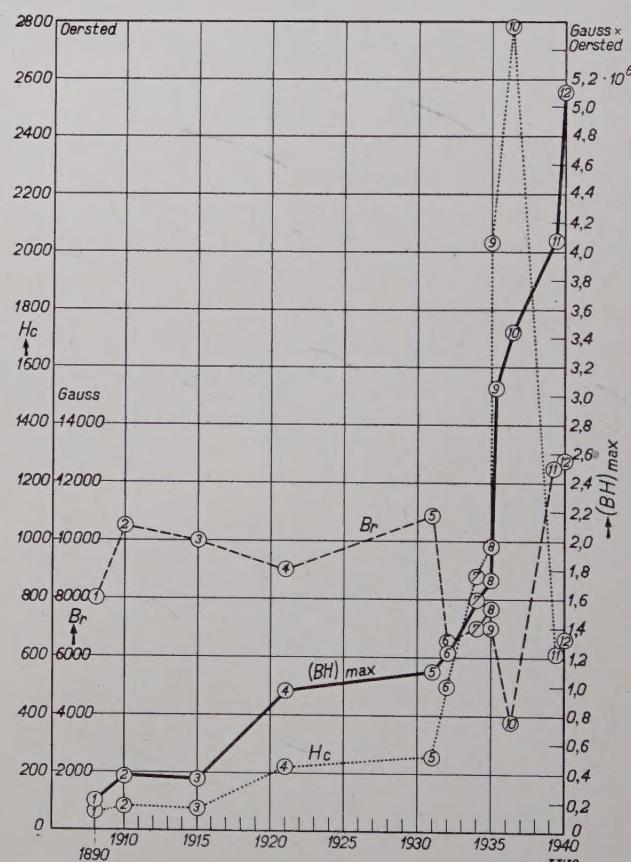


Fig. 4. The development of steels for permanent magnets during 50 years. Full lines  $(BH)_{\max}$ , broken line remanence, dotted line coercive force. The section from 1910 to 1938 is borrowed from E. Houdremont, Stahl und Eisen, 59, 37, 1939.

- |                         |                          |
|-------------------------|--------------------------|
| 1 carbon steel          | 7 Ni-Co-Ti steel (Honda) |
| 2 tungsten steel        | 8 "Ticonal" 2 and 2a     |
| 3 chromium steel        | 9 Fe-Pt steel            |
| 4 35% cobalt steel      | 10 Co-Pt steel           |
| 5 Co-Mo steel (Köster)  | 11 "Ticonal" 3.8         |
| 6 Ni-Al steel (Mishima) | 12 "Ticonal" 5.2         |

<sup>6)</sup> See for instance for the lifting power of the new steel, Philips techn. Rev. 5, 195, 1940.

<sup>7)</sup> See the article referred to in footnote <sup>2)</sup> page 32.

A clear picture of the development which has taken place in the last 50 years in the field of magnet steels is given in the diagram reproduced in fig. 4. Particular attention should be paid to the thick line which indicated the increase in magnetic power. Fig. 5 shows the result of this progress on the construction of loud speaker magnet systems. The total weight of the systems shown (magnet steel plus coupling pieces), all of which induce the same field in a given air gap, could be reduced in steps from 1314 g to 296 g by improvement in the magnet steel; at the same time the weight of the magnet steel itself has fallen from 580 g to 74 g. The most important data about the magnets shown will be found in the following table. It is clear that the

decrease in weight and volume of the magnet mean an important economy, not only for the loud speaker itself, but also for the construction of the whole radio set.

Kind of steel	$(BH)_{\max}$	Weight of magnet system	
	gauss-oersted	g	g
Cobalt steel (15% Co)	$0.6 \cdot 10^6$	580	1314
"Ticonal" 1	$1.2 \cdot 10^6$	325	703
"Ticonal" 2	$1.8 \cdot 10^6$	235	545
"Ticonal" 3.8	$4 \cdot 10^6$	104	326
"Ticonal" 5.2	$5.2 \cdot 10^6$	74	296

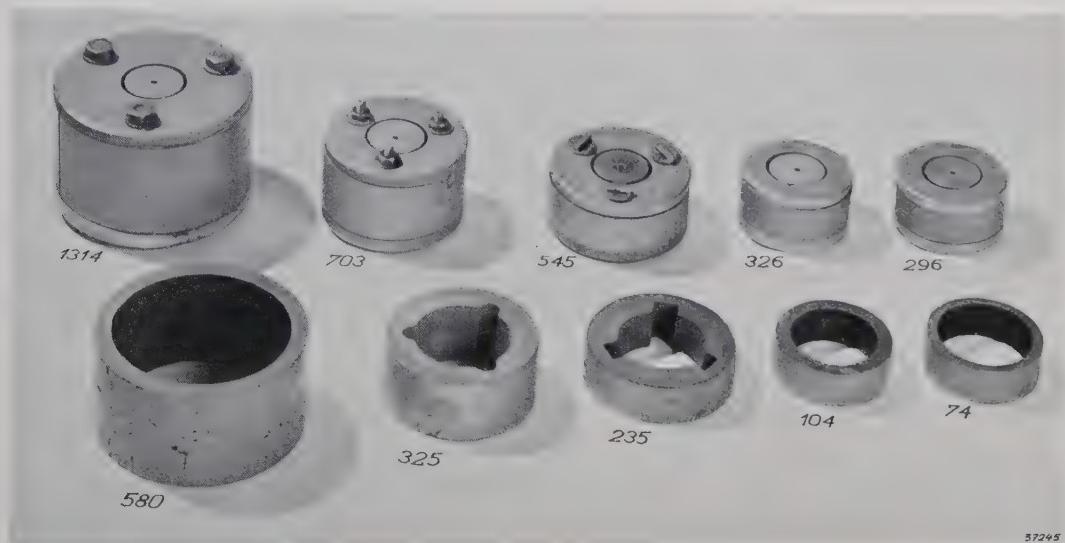


Fig. 5. A series of loud-speaker magnets which have the same field in a given air gap. The steadily diminishing size of the magnets and of the separately shown magnet steel rings gives an idea of the technical progress achieved in the course of years. The numbers indicate the weights in grams.

## A UNIVERSAL APPARATUS FOR X-RAY DIAGNOSIS

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An X-ray apparatus is described which can be used for fluoroscopy and photography of any object occurring in medical diagnosis. One of the principles of its construction was that in order to obtain the best possible exposures the focus of the X-ray tube must always be loaded up to the permissible limit. This led to the result that the regulation of the tube current must not be left to the user, but must take place automatically when the voltage and exposure time have been chosen. The realisation of this principle and its influence on the construction of the rest of the apparatus is discussed in detail. In conclusion the connection of different X-ray tubes with the apparatus is dealt with, as well as its operation, which is reduced to the very simplest manipulations.

In medical X-ray examinations two different methods are used: fluoroscopy and photography. In the first case the X-rays passing through the part of the body to be examined are allowed to fall upon a fluorescent screen, and the resulting shadow picture is examined directly by the doctor. In the second case the fluorescent screen is replaced by a photographic plate or film, against both sides of which a fluorescent foil is pressed. In general fluoroscopy is used for orientation or for preliminary diagnosis, while afterwards the photograph is used for making the final diagnosis and for securing an objective documentation.

According to the part of the body to be examined and the stoutness of the patient, fluoroscopy or photography must be carried out in different ways in order to obtain the best possible X-ray pictures. While in certain establishments, such as lung sanatoria, it is always the same objects (the lungs in this case) which are examined, and the X-ray installation can therefore be adapted exclusively to this special purpose, in other cases, such as non-specialized institutes, it is desirable to have an X-ray apparatus with which all kinds of very divergent examinations can be carried out. In this article we shall discuss such an installation, the Philips Medio-D apparatus, type 11 455, where the emphasis is laid on the requirement that its universal utility may not be at the expense of the quality of the X-ray picture obtained in each separate case.

### Specification of the requirements

Among the variables which can be controlled in making X-ray exposures, the following are of direct importance in designing an apparatus for X-ray diagnosis: the voltage on the X-ray tube, the tube current, the size of the focus which emits the X-rays, and the exposure time (loading time of the tube). In *table I* the way in which these variables can effectively be chosen is given for several of the most commonly occurring objects.

Although it would lie outside the scope of this article to give detailed reasons for the choice indicated, a brief explanation of the values given is necessary for a better understanding of the following.

Table I

Exposure technique for X-ray photographs of different parts of the body. The choice of the quantities here given is closely connected with the choice of the distance of focus to film, the kind of fluorescent foil and presence or absence of a so-called Bucky raster. It is assumed that for each of the techniques indicated these latter factors are also fixed. For the sake of simplicity, however, they have here been omitted, since they play no further part in the construction of the X-ray apparatus. The values hold for a tube with stationary anode. When a rotating anode is used, which may be loaded much more heavily (see below), considerably larger currents and shorter exposure times can be used.

Object	Voltage kV <sub>max</sub>	Current mA	Diameter focus mm	Exposure time sec
Lung	55	165	3,1	1/10
Stomach	80*)	140	3,1	1/8
Shoulder	55	35	1,7	2
Skull	80	30	1,7	2
Lumbar (transverse)	100	25	1,7	4

\*) By the administration of a paste containing barium, which is strongly absorbent, as a means of obtaining contrast, the voltage can here be given this high value.

The choice of the quantities mentioned is determined by a compromise between density, contrast and definition of the exposure obtained. Increasing tube voltage decreases the contrast because of the increasing hardness of the X-rays excited<sup>1)</sup>, it gives, however, a greater intensity on the film (greater density), since the energy converted in the tube, the efficiency of the excitation of the radiation and the penetration of the rays increase with the voltage. With increasing tube current also

<sup>1)</sup> See for instance Philips techn. Rev. 2, 317, 1937. For a more detailed treatment of what is presented here in a very much simplified form see for example Philips techn. Rev. 5, 258, 1940 and the literature there cited.

a greater density is obtained because of the increase of the X-ray intensity with the energy converted in the tube. This latter process is, however, limited by the heating of the anticathode: the material of the anticathode can only stand a limited load per  $\text{cm}^2$  of the focus (specific focal loading) without melting. When this highest permissible value has been reached, the X-ray intensity can only be further increased by taking a larger focus. At the same time, however, the definition of the picture decreases due to the larger half-shadow width. Finally the density also increases with the exposure time; but when it is a question of moving objects, such as lungs, stomach, etc., this is accompanied by a greater lack of definition.

The values of table I represent (for a given allowable loading of the focus) practically the most favourable compromise which is to be found under these opposing influences in the various cases. The way in which this compromise is arrived at for the properties of the objects to be photographed is now fairly clear: upon photography of moving objects such as lungs and stomach the exposure must be very short, so that a large focus is needed; in skull photography and the like, the exposure may be for several seconds, and therefore greater definition can be expected by the use of a smaller focus; with very absorbent objects (with large contrasts), such as bones, the voltage is made high, with weakly absorbing tissues, such as the lungs, low voltages are demanded, etc. One point is, however, fixed in all these cases: in order to reach an optimum result, the focus must be loaded up to its limit. The permissible loading (product of current and voltage) still depends upon the time of loading of the tube (exposure time): with short loading the load may be heavier than with a long time of loading. Therefore if two of the three quantities, current, voltage and time are chosen, for instance the voltage and the time, then the third, the current, may no longer be considered as an independent variable, but it is fixed by a relation which differs for every X-ray tube, an example of which is given in fig. 1.

If one compares the optimum attainable quality of the photograph for different X-ray tubes, then under otherwise similar conditions that tube will be the best in which the permissible specific focal loading<sup>2)</sup> is the highest.

The foregoing has referred to photography. As to fluoroscopy, one must always accept a poorer

quality of the X-ray picture, since the loading time is here very much greater (several minutes), and therefore the permissible loading of the tube much smaller<sup>3)</sup>. Moreover, the total X-ray dosage may not exceed a certain value for the safety of the patient. The best compromise attainable with the limited intensity between contrast and clearness of the picture can be found by the doctor himself during the examination by varying the voltage somewhat, to for instance 10 kV higher or lower than the value used for the photograph.

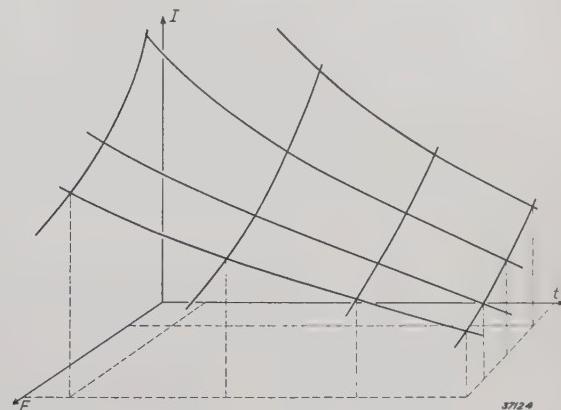


Fig. 1. Relation between tube current  $I$ , tube voltage  $E$  and loading time  $t$ , when the focus is loaded up to the highest permissible temperature. The surface drawn is for an X-ray tube with rotating tungsten anticathode and for loading with so-called commutated alternating current (4 valve connection).

We may now make several stipulations which must be met in the construction of the universal apparatus for diagnosis. The tube voltage must be variable between several hundredths of a second and several seconds; the current must always be such that the focus is fully loaded, which means a variation between 25 and 500 mA, according to the tube used and the object to be examined. It is obvious that for obtaining comparable photographs the values chosen must be easily reproducible.

In addition to these requirements, which are connected with the possibilities of variation of the exposure technique, there are several others connected with the placing of the patient and the method followed in the examination, which exert their influence on the construction of the apparatus. The X-ray tube and the film holder must be hung on a standard which permits a rapid and accurate adjustment of focus and film with respect to the patient. For the examination of different organs different standards will sometimes have to be used,

<sup>2)</sup> By specific loading is here meant the loading per  $\text{cm}^2$  of the "apparent" focus; see in this connection Philips techn. Rev. 3, 262, 1938.

<sup>3)</sup> The loading limit here is not set by the danger of melting of the anticathode at the focus, but by the danger to which the glass parts of the tube are exposed by too great general heating of the anticathode.

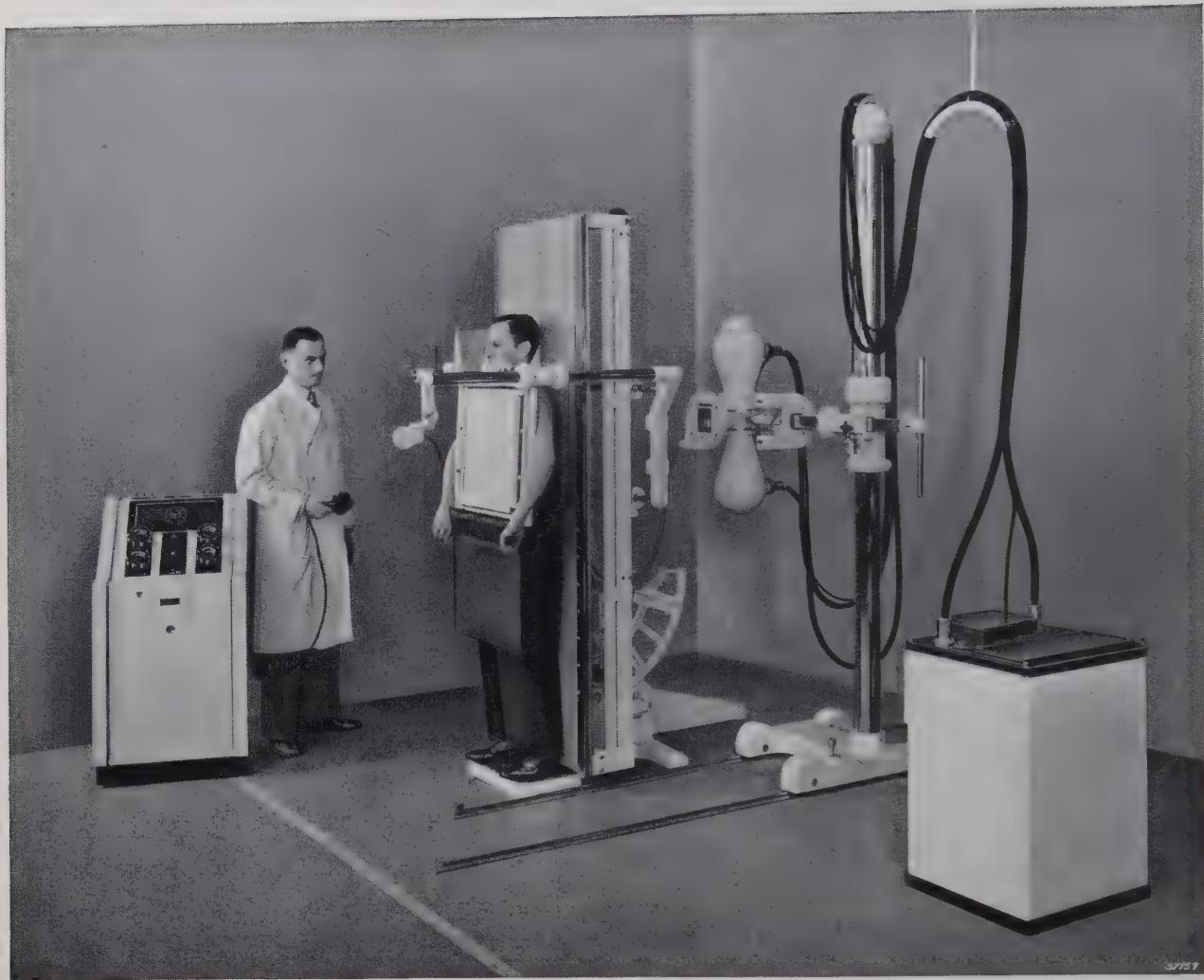


Fig. 2. View of the whole X-ray apparatus at the moment when a lung exposure is being made. On the right the iron tank filled with oil containing the high-voltage generator; on the left the operating desk. In the middle the standard which bears the fluoroscope screen or the film holder, behind that the X-ray tube hung on a movable column.

each with its own tube. The switching arrangements of the tube and any auxiliary apparatus, as well as the adjustment of the exposure quantities must be so simplified that the attention of the doctor is not thereby distracted. In certain cases, such as stomach examinations, it is also desirable by means of fluoroscopy to be able to determine the moment at which the object has taken on the position or shape which is to be fixed on the photograph. The apparatus must then be so arranged that the exposure can take place as quickly as possible after the fluoroscopy. In connection with this the variation of the voltage in fluoroscopy may not affect the previously made adjustment for the exposure, etc.

We shall now show how these different requirements are met in the apparatus to be described.

#### General description of the apparatus

The apparatus consists chiefly of the tube with standard, a high-voltage generator for supplying

the tube, a timing switch for switching the tube load on and off, and different regulatory devices which are combined in an operating desk. In fig. 2 a photograph of the complete installation is given, while fig. 3 shows the general plan of the connections.

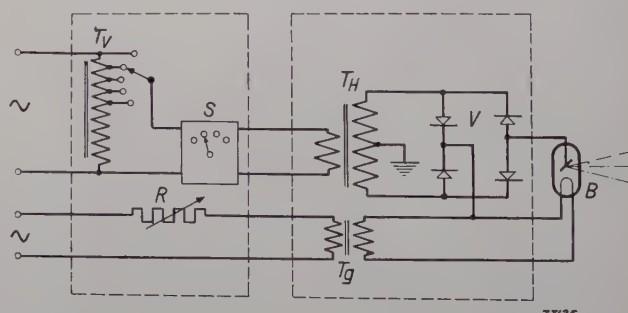


Fig. 3. Connections of the apparatus (very much simplified).  $T_H$  high-voltage transformer,  $V$  rectifier valves,  $B$  X-ray tube,  $S$  timing switch,  $T_v$  auto-transformer for regulating the tube voltage,  $T_g$  heating-current transformer,  $R$  resistance for varying the tube current.

The high-voltage generator contains a transformer connected to the local mains, which furnishes the required high-voltage of  $E_{\max} = 100$  kV. This voltage is rectified with four valves in the familiar Grätz connection, so that a pulsating D.C. voltage with a peak value of 100 kV is obtained on the tube (fig. 4). The variation of the tube voltage is obtained by changing the primary voltage of the high-voltage transformer with the help of taps on an intermediate autotransformer. The heating current of the tube is provided by a separate heating-current transformer; by means of an adjustable resistance in series with the primary winding the heating current, and with it the electron emission of the cathode, and thus the current through the X-ray tube, can be varied. The desired exposure time is finally obtained with the help of the above-mentioned timing switch which will be described below, and with which, it may be mentioned, the loading time of the tube can be adjusted between  $1/50$  sec and 8 sec in steps.

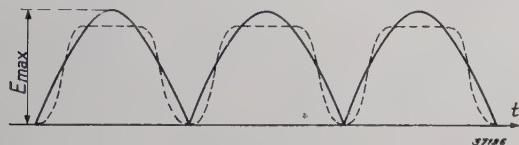


Fig. 4. Variation of the tube voltage with the time. The broken line gives the variation of the current which is in phase with the voltage. In each half period the current reaches a saturation value at a certain voltage. This current is given by the cathode emission.

#### The automatic character of the adjustment

In the above we have seen that when optimum results are desired the tube current must not be considered as an independent variable, but that with voltage and loading time determined it is fixed for a given tube by a relation as in fig. 1. In the case of the X-ray apparatus developed by Philips the obvious conclusion has been drawn that in photography the current should not be regulated by the operator, but upon regulation of the voltage (which mainly determines the contrast) and the loading time (which determines the lack of sharpness due to motion) it must automatically take on the corresponding highest permissible value.

Such an automatism can in principle be realized in a very simple way, see for example fig. 5.

To the axis of the voltage regulator is coupled a "pre-selector", i.e. an arm which can connect one end of the primary winding of the heating-current transformer successively to as many "main selectors" as there are voltage steps. The arms of the main selectors are all coupled with the axis of the regulator of the loading time, and every

main selector can continue the above-mentioned connection with as many taps of the heating-current resistance as there are time steps. If the apparatus has  $m$  voltage and  $n$  time steps,  $m \times n$  taps are made on the heating-current resistance; these taps are so arranged when the whole installation is adjusted that for each of the  $m \times n$  possible combinations of voltage and time values the proper current value is obtained.

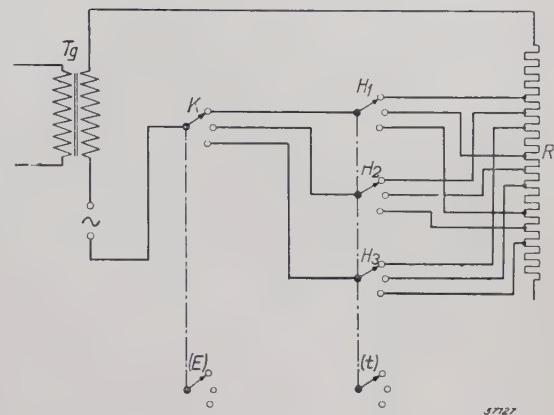


Fig. 5. Diagram showing the principle of the automatic adjustment of the tube current.  $T_g$  heating-current transformer,  $R$  resistance with as many taps as there are possible voltage-time combinations.  $K$  pre-selector coupled with the voltage regulator ( $E$ ).  $H_1, 2, 3 \dots$  main selectors coupled with the time regulator ( $t$ ).

The voltage must be adjustable in steps of about 2.5 kV; for the whole range of variation from 50 to 100 kV, therefore, about 20 voltage steps are needed. The same number of steps is needed for the exposure time, so that there would be no fewer than 400 taps on the heating-current resistance. Fortunately it is found in practice that a considerably smaller number is sufficient. The  $E$ - $I$ - $t$  surface of fig. 1 can be approximated by a stepped surface like that shown in fig. 6. All the voltage steps are here divided into three groups, and the

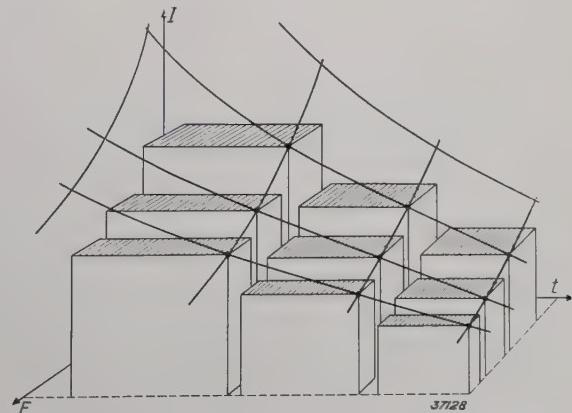


Fig. 6. Approximation to the curved surface of fig. 1 by a stepped surface. On the cross-hatched plane surfaces of the subdivisions the current is constant.

same is done with the time steps. For each voltage group in the automatic arrangement there is one main selector which selects one tap for each time group<sup>4)</sup>. One current value is thus selected for each of the nine group combinations. The highest permissible loading is now only attained for the highest voltage and the longest time of each group combination. At lower voltages and with shorter times in the same group the loading may remain as much as 30 per cent below the permissible value; no important difference in the quality of the exposure compared with the optimum results from this fact, however.

For fluoroscopy a variable resistance operated by hand is connected in the heating-current circuit. By means of a series resistance the tube current is prevented from ever increasing above the permissible value during the fluoroscope examination.

#### The voltage loss

Until now we have represented the case as if the voltage on the tube could be adjusted quite independently of the tube current. Actually account must be taken of the fact that upon flow of current through the tube a certain voltage loss occurs which increases with the current. This loss, which in certain apparatus may amount to 20 kV, is caused by the resistances of the high-voltage transformer, the switch arrangement, the connection lines to the generator, etc. and by the voltage drop in the rectifiers. It would of course be possible to compensate for the voltage loss simply by a correspondingly higher setting of the transformer voltage. This has, however, disadvantages connected with the automatism here employed. If for instance an exposure time of  $\frac{1}{5}$  sec is desired with a tube voltage of 60 kV, the automatic arrangement provides a tube current of 260 mA for a given tube. Suppose that the voltage loss here amounts to 20 kV, the transformer voltage must then be 80 kV (peak values are meant in every case). If the operator now raises the voltage one step, i.e. to 82.5 kV, the following voltage group is reached, where with  $\frac{1}{5}$  sec a current of only 210 mA is provided; the voltage loss here is considerably less, 16 kV for instance, the tube voltage is therefore  $82.5 - 16 = 66.5$  kV. The whole voltage range between 60 and 66.5 kV is thus traversed in one step without the possibility of a finer adjustment.

In order to avoid this difficulty attempts were made to limit the voltage loss as much as possible in the whole apparatus. To this end in the first place a heavy high-voltage transformer with only slight resistance is used. Likewise for the voltage regulation an autotransformer with thick windings is taken and a rotating switch with broad contacts and thick connections. Furthermore for the rectifier connections hot-cathode valves with gas filling are used which have a voltage drop in the transition direction of only about 50 volts<sup>5)</sup>. A not inconsiderable part of the remaining voltage loss is caused by the resistance of the local mains themselves, since the apparatus can take up for short times energies up to 15 kW. Since this mains resistance may vary very much in different installations, while it is nevertheless desirable that the same voltage losses and thus the same exposure values should be obtained, an additional variable resistance in series with the mains connection is included, which supplements the local mains resistance to give the same value for all installations. In fig. 7, which shows several other details of the primary circuit, this is illustrated more fully. The voltage loss in the mains at 260 mA now always amounts to 4 kV; added to this are 3 kV loss in the high-voltage transformer, 0.1 kV in the valves, etc., giving a total loss of about 10 kV.

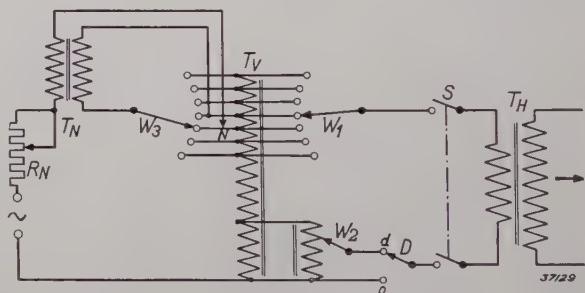


Fig. 7. The primary voltage of the high-voltage transformer  $T_H$  is regulated by selecting different taps of the auto-transformer  $T_V$  with the contact arm  $W_1$ . For fluoroscopy switch  $D$  is placed on  $d$  ( $o$  is for photography), and the voltage can be varied an additional  $\pm 10$  kV with the help of  $W_2$ . By suitable choice of the connection  $N$  the apparatus can be used at different nominal mains voltages (between 150 and 440 V). In order always to obtain the same high-tension values with a given setting of  $W_1$  and  $W_2$  upon variation in the mains voltage, the input voltage of the auto-transformer can be varied slightly further with the help of the auxiliary transformer  $T_N$  and the switch arm  $W_3$ .  $S$  main switch,  $R_N$  variable resistance with which the voltage loss can be made equal for all installations.

#### Reproducibility of the adjustment

The type of automatic arrangement described affects the construction of the whole apparatus, not

<sup>4)</sup> Actually the automatic arrangement in the apparatus described is slightly different; for the sake of simplicity, however, this simple description may be considered as a basis.

<sup>5)</sup> These high-voltage valves have already been described in Philips techn. Rev. 1, 8, 1936.

only because of the requirement of a low voltage loss, but also because of the high requirements made of the reproducibility. Since the tube current can here be varied by changing the heating current, it is necessary in the first place that the electron emission of the hot cathode should be absolutely constant. When the emission decreases somewhat during the lifetime of the tube, the quality of the photographs suffers. In the regularly occurring checks therefore the taps on the heating-current resistance must be regulated anew and adapted to the changed emission properties. More dangerous than this gradual drift would be the variations of the heating voltage and of the resistances in the heating-current circuit occurring during operation, since the emission depends very closely upon the heating current and since instead of a decrease in the quality of the picture, an overloading of the tube could occur. The heating voltage is kept constant, *i.e.* made independent of mains voltage fluctuations (and of any mains voltage fall due to the high current during exposure) by connecting a "stabilizer" in front of the heating-current transformer<sup>6)</sup>. The resistances in the heating-current circuit must above all be protected from becoming too hot, which would cause the specific conductivity to vary. This is especially true for the heating-current transformer which is housed together with the high-voltage transformer and the rectifiers in an oil tank, and which therefore might become too hot due to the proximity of the latter. Thanks, however, to the above-mentioned heavy build of the transformer and to the use of gas-filled valves in which oxide cathodes can be used and which therefore give the necessary emission with about 10 W heating-current energy, the heating up of the whole generator container is reduced to a harmlessly low level.

#### The timing switch

Like current and voltage, the loading time must be very accurately reproducible, to within a few per cent, for instance, in order to load the focus correctly. This is no simple condition when it is kept in mind that it is here a question of the switching of powers of up to 15 kW (according to the X-ray tube employed) during times which must be able to be adjusted between several hundredths of a second and several seconds.

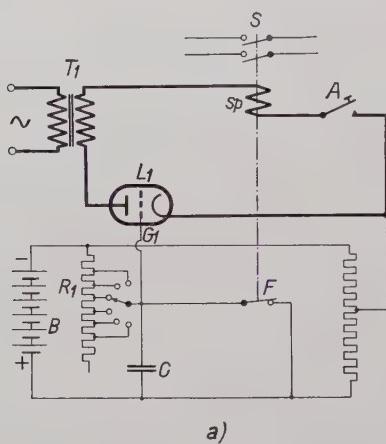
The circuit diagram of the timing switch developed for this purpose is given in fig. 8b. In order to make its action clear, let us consider first the very much

simplified diagram of fig. 8a. The switching of the tube voltage (main switch *S*) takes place by means of a relay *Sp* which is excited by a transformer *T*<sub>1</sub> via the relay valve *L*<sub>1</sub>. Such a relay valve (gas-filled triode) can only ignite when the grid as well as the anode have a sufficiently high voltage with respect to the cathode, and only be extinguished when the anode voltage becomes negative (or falls below a certain value). As long as the push-button switch *A* is open, the grid *G*<sub>1</sub> is positive with respect to the cathode. After *A* is closed therefore the valve ignites as soon as the anode is positive enough; the relay receives current and closes the switch *S*, the loading of the X-ray tube begins. As the supply A.C. voltage passes through zero the relay valve is extinguished, while a half period later it again ignites. If we now first assume that the time of opening of the relay is so long that the currentless periods (during which the anode of *L*<sub>1</sub> is negative) are thereby bridged over, then the high-voltage circuit will always remain closed. Simultaneously with the closing of the main switch *S*, however, the relay has opened the auxiliary switch *F*, so that the battery *B* begins to charge the condenser *C* via the resistance *R*<sub>1</sub>. The grid *G*<sub>1</sub> connected to the upper condenser plate is hereby gradually made less positive, and after a certain interval of time, which can be regulated by adjustment of *R*<sub>1</sub>, it becomes negative with respect to the cathode. Now the reignition of the relay valve after the next negative period of the anode voltage is no longer possible, the relay *Sp* falls out, the loading of the X-ray tube is ended. (Special measures have been taken, so that the switch does not "repeat", *i.e.* so that it does not immediately switch on again directly after the restoration of the initial state).

By the variation of *R*<sub>1</sub> (and if necessary of *C*) the loading time can be regulated within wide limits. The reproducibility would, however, by no means be satisfactory. According as the moment when *A* is switched on falls at the beginning or end of the positive period of the alternating current, the loading time may already vary by  $1/100$  sec (a half period). Still worse are the differences which may occur by the more or less rapid falling out of the relay, which, according to the above, must work with a relative time lag. These disadvantages are avoided as follows in the actual construction (fig. 8b). For the excitation of the relay, a second relay valve *L*<sub>2</sub> is introduced, whose grid is normally kept negative by the D.C. voltage source *B*<sub>1</sub>. If, however, the valve *L*<sub>1</sub> is extinguished, a voltage surge is caused in the secondary winding *Sp*<sub>2</sub> of the relay *Sp*, which just makes the grid of *L*<sub>2</sub> pos-

<sup>6)</sup> See Philips techn. Rev. 2, 276, 1937.

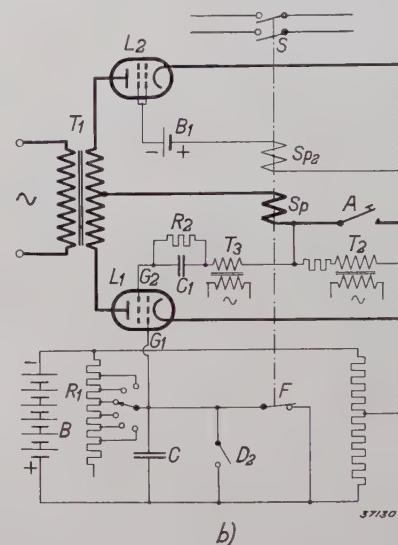
itive at the moment when the anode voltage of  $L_2$  is positive, so that  $L_2$  now ignites and transmits current for half a period. The valve  $L_1$  thus always "follows" the valve  $L_2$  and supplements the direct current impulses produced by the latter in the intermediate half periods. It is not necessary for this reason to give the relay a long opening time for bridging over these half periods. On the contrary, by making the opening time as short as possible the fluctuation in this time is also decreased and the reproducibility increased.



a)

### The connection of different X-ray tubes

The explanation given at the beginning on the technique of exposure leads to the conclusion that for every object a definite optimum size of focus should be chosen. The size of the focus in a given tube is permanently fixed by the shape and dimensions of the cathode. Thus for every kind of object one would need a separate X-ray tube with a definite cathode. For smaller hospitals where financial reasons make this condition a handicap, a tube has been constructed which contains



b)

Fig. 8. Timing switch. a) Principle of the timing arrangement: after setting the push button switch  $A$  the relay valve  $L_1$  ignites, the relay  $Sp$  switches the high-voltage transformer in through  $S$ , but at the same time opens by means of  $F$  the short circuit of the condenser  $C$ . The speed with which  $C$  is charged by the battery  $B$ , i.e. the setting of the variable resistance  $R_1$ , determines the time during which the relay valve can transmit current.

b) More complete diagram. In these connections "isochronous" switching of the relays takes place at the zero points of the voltage. The condenser  $C_1$  in the stationary state ( $A$  open) is charged through the auxiliary transformer  $T_2$ , and, thanks to the rectifying action of the hot cathode, in such a way that the second grid  $G_2$  of the relay valve  $L_1$  is negative. Upon closing  $A$  therefore the relay valve cannot immediately ignite. Due to the fact, however, that the charging voltage of  $C_1$  is now short-circuited,  $C_1$  discharges gradually over  $R_2$ , the potential of  $G_2$  slowly rises to cathode potential. Through the small transformer  $T_0$  an A.C. voltage acts on  $G_2$  which causes  $G_2$  to become positive just at the moment at which the anode also becomes positive. At this moment therefore the valve ignites, independent of the moment when  $A$  is closed. Switching off always occurs "isochronously" of itself, since the relay valves are always extinguished, independent of the grid voltage, when the anode voltage becomes negative.

In order to obtain a short opening time the movable parts of the relay must be kept light. This would not be possible if the relay had to switch over the whole energy, but in that case heavy contacts would be necessary because of the wear. Therefore provision has been made that the switching on and off takes place "isochronously" i.e. always at moments when the voltage (and therefore in our case the current also) passes through zero. At the same time by this device the previously mentioned inaccuracy due to the arbitrariness of the moment of closing switch  $A$  is eliminated. The way in which the isochronous switching is ensured is explained further in the text under fig. 8.

two separate hot cathodes which can be used at will. By this means at least two different foci are available, for instance one of 3.1 mm diameter for moving objects (lungs, stomach, etc.), and one of 1.7 mm diameter for stationary objects (skull, shoulder, etc.). A better solution is the use of an X-ray tube with rotating anode ("Rotalix" tube<sup>7</sup>)) in which the permissible specific focus loading is a factor 6 to 10 higher than with a stationary anode, and with which therefore even with a small focus sufficient intensity for exposures of moving objects is obtained.

<sup>7</sup>) See Philips techn. Rev. 3, 292, 1938.

The apparatus here described is specially designed for connection with these two tubes, and the generator is provided to two sets of cable connections, the choice between them being made with a built-in high-voltage switch. Several problems were encountered, particularly in connection with the cathode supply. The cathode, and with it the secondary winding of the heating-current transformer are under high tension, since the middle point of the tube voltage is earthed in order to have to insulate only against half the high-voltage with respect to earth. The fact that the cathode is under high tension led on the one hand to the heating-current transformer being housed in the oil tank of the generator (see above) and on the other hand it made it desirable to carry out as few switching manipulations as possible in the cathode circuit. Therefore three heating-current transfor-

mers are housed in the generator (see fig. 9). The secondary windings of two of them are connected to a post of one set of high-voltage connections and can supply the two cathodes of a tube with double focus. The secondary winding of the third is connected to a post of the second set of high-voltage connections. Thus upon passing over to a different tube or focus switching need only be performed in the primary circuits of the heating-current transformers.

In addition to the switching over of the high voltage and the cathode supply, care must also be taken that the automatic arrangement of the tube current regulation is correct for each tube (or each cathode). This is realized in a simple way by using a separate heating-current resistance for each tube (or cathode), the nine taps of which resistance are adjusted separately. Fig. 10 shows how these automatic units are assembled in the operation desk. Upon connection of still other X-ray tubes with the apparatus (for which a separate high-voltage commutator is necessary) more of such units, up to a total of six, can be built in.

The commutation of the high-voltage takes place simultaneously with the commutation of the cathode, of the series resistance for the fluoroscope heating current (see above) and of the automatic arrangement, by means of a relay, all of which are operated at once by a tube selector mounted on the desk (fig. 11).

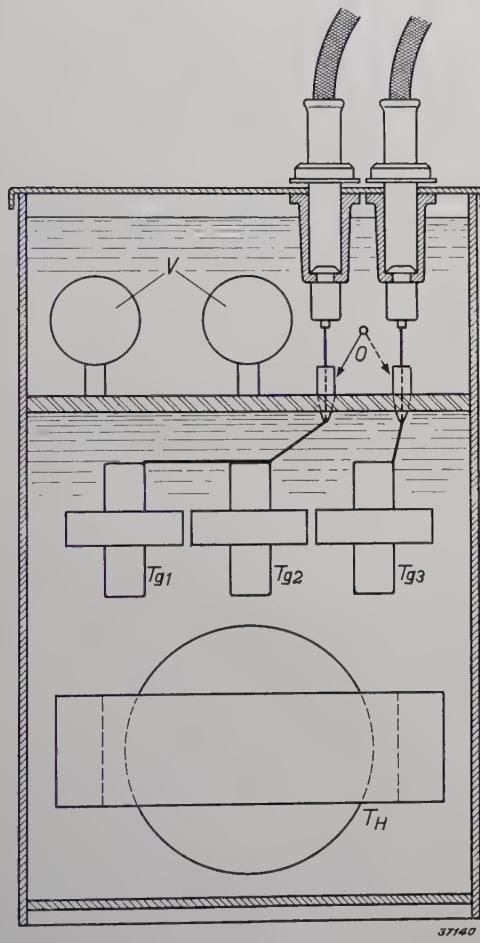
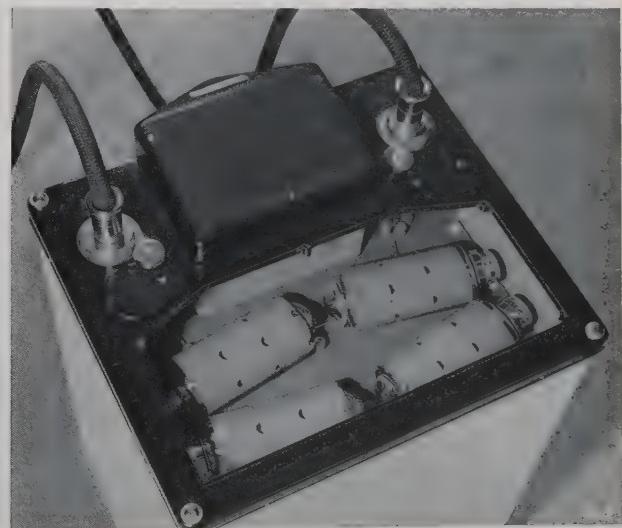
*a*

Fig. 9. a) Assembly of the high-voltage transformer  $T_H$ , the three heating-current transformers  $T_g$  and the four rectifier valves  $V$  in an iron container filled with oil (dimensions about  $80 \times 50 \times 50$  cm). Since the valves must be accessible for control, replacement, etc., while the transformers, in whose case the insulating oil also serves as impregnating medium, must remain carefully closed, the container is divided into two parts by a horizontal partition. In fig. 9b a view is shown of the upper part (not yet filled with oil) in which the rectifiers are housed. In this part is also the high-voltage switch  $O$  for the two sets of connections.

*b*

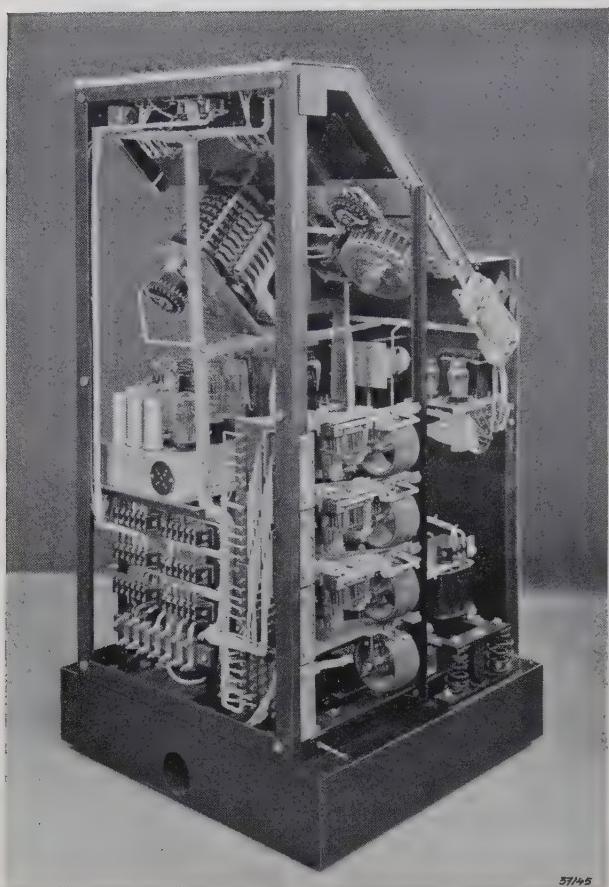


Fig. 10. View of the interior of the operating desk. To the right in front may be seen three "automat" units mounted one above the other, i.e. heating-current resistances with switch contacts for three different cathodes. If more tubes are connected to the apparatus a unit is added for each cathode. Under the cover are the rotating switches of the voltage regulator, etc. To the left below, the timing switch.

### Using the apparatus

The apparatus is so arranged that after switching on the mains voltage everything is normally ready for fluoroscopy: the tube receives a small heating current, the separate voltage regulator ( $W_2$  in fig. 7) is switched on, the timing switch is out of action ( $D_2$  in fig. 8b closed). In the meantime, however, the desired voltage and time for an exposure can already be set, without affecting the fluoroscope image.

For photography, in addition to setting the various switches ( $D$  in fig. 7,  $D_2$  in fig. 8b, measuring range of the mA and mA-sec meters  $K$  and  $L$  on the operating desk, etc.) the hot cathode must furnish the higher emission chosen, and when a "Rotalix" X-ray tube is used the anode must have reached its working speed. This requires some time,

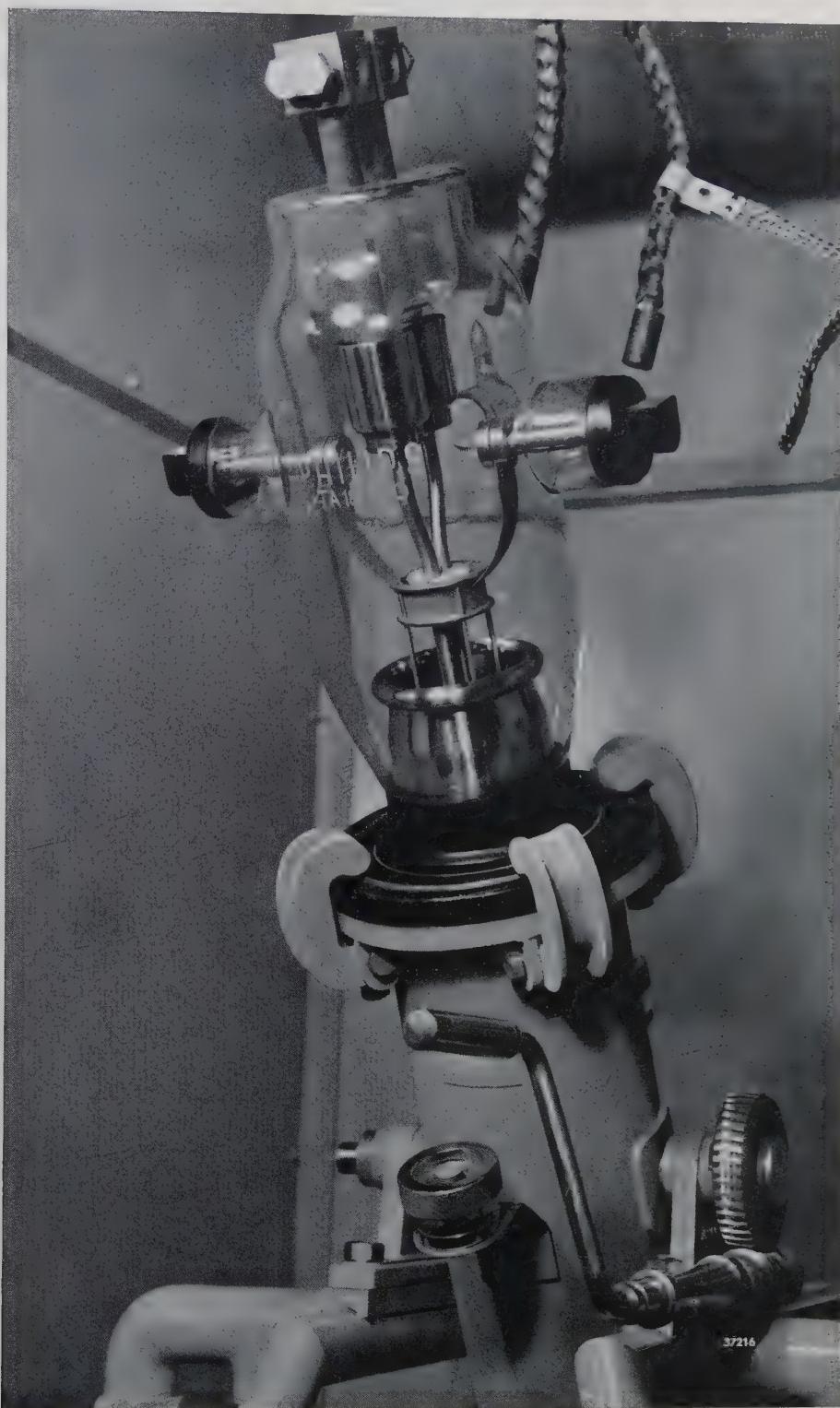
about 0.8 sec in both cases. The doctor using the apparatus need not bother with all these things, however: all switching operations are accomplished automatically by pressing on the knob of a hand switch, while a retarding relay provides that the timing switch only begins to work after 0.8 sec.

Other mechanisms also which are involved with photography can be coupled with the hand switch, for instance a moving raster for attenuating the scattered rays or a mechanism for bringing the film holder into position. This is necessary particularly in the so-called stomach series examination which was touched upon at the beginning. In this case by pressing the knob "photography" a film is also inserted in front of the fluoroscope screen by an electrically operated mechanism, so that between the fluoroscopic examination and the photographic exposure no more than the 0.8 sec mentioned elapses. In this way the required operations are reduced to the adjustment beforehand of time and voltage and the pressing of the knobs "fluoroscope" and "photograph".



Fig. 11. The switchboard of the operating desk. By means of the so-called tube selector  $F$ , high-voltage, heating voltage, automatic arrangement, etc. are all switched over at once to the X-ray tube to be used. The other knobs serve for the regulation of the time ( $G$ ), the coarse and fine regulation of the tube voltage ( $B$  and  $C$ ), the regulation of voltage and current for fluoroscopy ( $E$  and  $D$ ) and the correction of the mains voltage ( $A$ ; checked with voltmeter  $H$ ). On the left hanging on a hook, a hand switch with which the doctor standing at any desired distance from the desk can switch the apparatus on and off in fluoroscopy or photography.

## THE WATERCOOLED TRANSMITTING VALVE TA 18/100



TA 18/100 is a watercooled transmitting valve, which in H.F. class C telegraphy adjustment supplies 100 kW and about 38 kW in the carrier wave, using anode modulation.

The maximum allowable anode dissipation amounts to 70 kW. Filament voltage 33 V, filament current 207 A.

Overall length without cooler 120.5 cm, with cooler 133.3 cm.

The photograph shows this valve in a special arrangement, as used in the new Netherlands broadcasting system, which facilitates easy interchangeability of valves.

# THE RECORDING OF DIAGRAMS WITH THE ELECTRICAL PRESSURE INDICATOR

by P. J. HAGENDOORN and M. F. REYNST.

531.787.9

Following a previous article in this periodical which gave a detailed description of the electrical pressure indicator for internal combustion engines developed by Philips, a further study is here made of the different kinds of diagrams which can be recorded with this apparatus. The detailed construction is given of the piston-stroke recorder with which a deflection of the cathode ray proportional to the displacement of the piston is obtained. For the routine testing of large engines, in Diesel stations for instance, special devices have been developed which are also briefly discussed.

With the help of the pressure indicator GM 3 154, which was described in a previous article<sup>1)</sup>, the variation of pressure in the cylinder of an internal combustion engine can be made visible on the screen of a cathode ray tube. The pressure variations are first converted into capacity variations of a condenser, one of whose electrodes is formed by a membrane in the wall of the cylinders (pressure recorder). The capacity variations obtained are used to modulate a carrier wave from which, after amplification and rectification, the required voltage for the vertical deflection of the fluorescent spot is obtained. As to the horizontal deflection, two methods may be used: it may be made proportional to the time or to the displacement of the piston, thus to the volume (more exactly: to the increase in the volume) of the combustion chamber. In this article we shall study the way in which these two types of diagrams and all kinds of variations of them are obtained, as well as the various auxiliary apparatus which have been developed for this purpose.

## Pressure-time diagrams

A horizontal deflection of the cathode ray proportional to the time is obtained by applying to the proper set of plates of the cathode ray tube a voltage of the form given in fig. 1. In order to generate this sawtooth voltage a time-axis generator is used in the pressure indicator which corresponds exactly

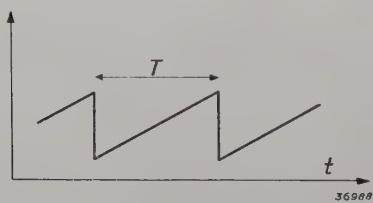


Fig. 1. Sawtooth voltage for the recording of diagrams with the time as abscissa.

to that of the cathode ray oscilloscope GM 3 156, which has recently been described in this periodical<sup>2)</sup>.

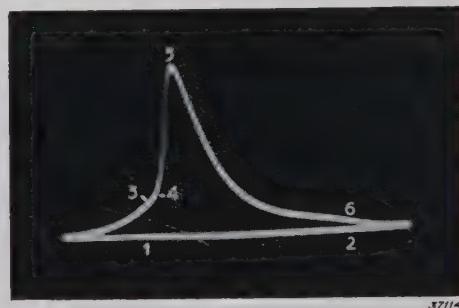


Fig. 2. Normal pressure-time diagram of a four-stroke engine recorded with the pressure indicator GM 3 154. The time base is equal to one revolution. This photograph, like those of figs. 3, 4, 5, 12, 13 and 14, has been put at our disposal by the Batavia'sche Petroleum Maatschappij, Testing station, Delft. Fig. 12 in the article referred to<sup>1)</sup> is also from this testing station.

Fig. 2 shows a normal pressure-time diagram of a four-stroke engine recorded in this way. In order to obtain a stationary image on the fluorescent screen it is necessary that the period of the time base ( $T$  in fig. 1) should be exactly equal to half the fundamental period of the diagram, thus to the time necessary for one revolution around the crank-shaft. By regulation of the time-axis generator the period of the time base can be set approximately at the desired value, while exact synchronisation with the engine is realized by an extra voltage surge which, with Diesel engines, is supplied once per revolution via a contact disc mounted on the crank-shaft to the time-axis generator, and with petrol engines, by means of the voltage impulse of the sparking plug.

In the diagram of fig. 2 the following processes may be distinguished: the sucking in of the gas mixture into the combustion chamber (1-2) at a

<sup>1)</sup> P. J. Hagendoorn and M. F. Reynst, An electrical pressure indicator for internal combustion engines, Philips techn. Rev. 5, 348, 1940.

<sup>2)</sup> S. L. de Bruin and C. Dorsman, A cathode ray oscilloscope for use in tool making, Philips techn. Rev. 5, 277, 1940.

pressure slightly less than one atmosphere, the compression of the air (2-3), at 3 the ignition and beginning of the combustion (3-4), the combustion (4-5), at which the pressure quickly reaches a peak value (5), the expansion of the burned and heated gases (5-6), the driving out of these gases (6-1).

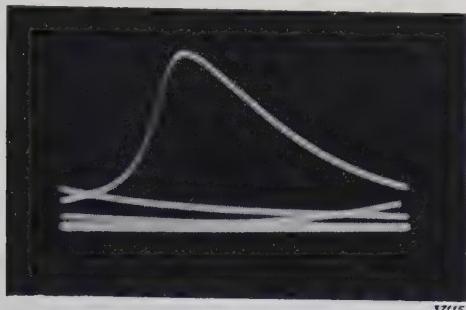


Fig. 3. The same diagram as fig. 2 recorded on a larger scale. The time base here was made equal to half a revolution of the crank-shaft.

While the sucking in, compression, expansion and driving out are relatively simple processes, more or less fixed by the dimensions of the cylinder, the valve openings, etc., the pressure variation from 3 to 5, *i.e.* the process of combustion, depends upon many influences which are not directly controllable. Here therefore deviations may most easily occur from the normal action, and here therefore the control by means of the diagram is most important. With the time-axis generator the diagram can also be recorded on a larger scale, so that the details of the part in question are clearer. For this purpose the time base is adjusted to a length equal to a half, a third, a fourth, ... revolution. One then obtains, for example, on the fluorescent screen an image like that of fig. 3. The synchronization arrangement here also provides that the image is stationary.

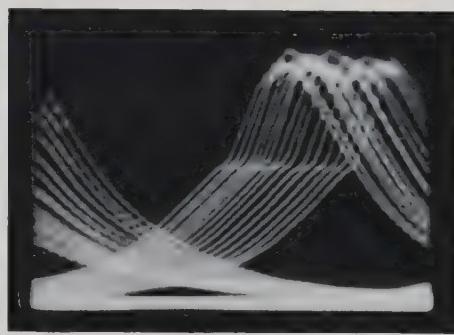
In the case of internal combustion engines one of the most feared phenomena is so-called detonation which is manifested by the appearance of vibrations in the expansion lines (see fig. 4). Not only due to



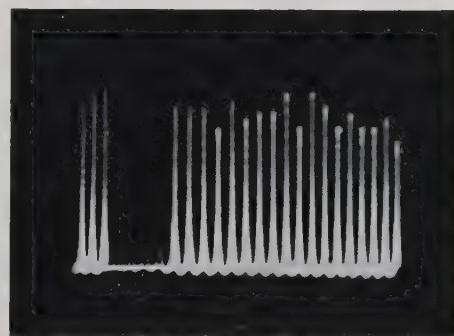
Fig. 4. Pressure-time diagrams with detonation vibrations on the expansion line.

too heavy loading, incorrect composition of the gas mixture, carbon deposit in the cylinder and similar causes, detonation may also occur due to too high compression and irregular ignition, resulting for instance from too high a temperature of the cylinder wall (insufficient cooling).

In certain cases it may be desirable to employ no synchronization. The following is an interesting example. If the time-axis generator is set as in fig. 2 but synchronization is omitted, the variation of pressure for the successive revolutions will not always appear at the same spots on the fluorescent screen but will gradually shift, see fig. 5a. In the



a



b

Fig. 5. a) Photograph of a series of successive pressure-time diagrams recorded without synchronization. By the gradual shifting of corresponding points of the diagrams the variation of the peak pressure and of the compression pressure is shown as a function of the time. b) A series of successive, very much compressed pressure-time diagrams. The variation of the top pressure can here also clearly be seen. The photograph of fig. 5a as well as those of fig. 6, 17 and 18 were kindly put at our disposal by the Testing Department of the N.V. Werkspoor of Amsterdam.

photograph of such a non-stationary image the variation with time of the peak pressure is clearly distinguishable, and also that of the compression pressure and the ignition, so that the engine constructor can judge on this basis whether there are irregularities in the combustion. Another possibility of obtaining a picture of the variation of the peak pressures is to make the time base very long, *i.e.* to make the fluorescent spot move only very slowly in a horizontal direction, so that a

large number of (very compressed) diagrams are traced side by side, see fig. 5b.

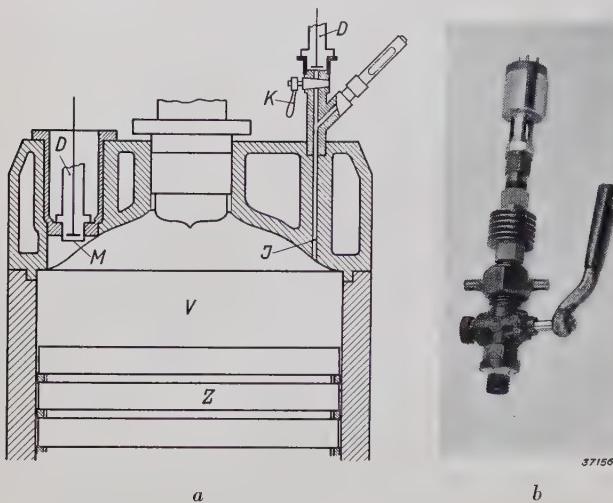


Fig. 6. If the membrane  $M$  of the pressure recorder  $D$  cannot be inserted into the cylinder wall itself (a, left) it must be connected with an indication channel  $I$  (a, right). In this channel gas vibrations as in an organ pipe may occur.  $Z$  piston,  $V$  combustion chamber,  $K$  indication tap. It must be mentioned incidentally that in this method of connection too great a heating of the membrane may sometimes also occur, since it cannot profit by the cooling by the (water-cooled) cylinder wall. In this case cooling fins must be constructed on the connection piece as may be seen in the photograph (b).

Vibrations on the expansion line of the diagram may also occur due to other causes than detonation. The pressure recorder often cannot be inserted directly into the wall of the cylinder, but must be mounted with a connecting piece on the indication channel (fig. 6) with which the cylinders of large engines are provided as a rule. Due to the sudden increase of pressure during the combustion (4-5 in fig. 2), characteristic vibrations can be excited in the gas column in the indication channel in the same way as in an organ pipe, which vibrations also appear in the pressure indicator diagram. By determining the frequency of the vibrations it is often possible to discover whether one is concerned with genuine detonation vibrations or with organ pipe vibrations. In the diagram of fig. 7 for instance, it



Fig. 7. Pressure-time diagram with vibrations on the expansion line, which, upon determination of the frequency, were found to be caused by organ pipe vibrations in the indication channel.

is found by measurement that the fundamental period of the vibration amounted to 0.037 times the duration of one revolution. The engine made 1600 r.p.m., the fundamental frequency of the vibration was therefore 720 c/s. On the other hand the length of the indication channel was 20 cm, and since in ordinary organ pipe vibrations the wave length of the fundamental tone is approximately four times the length of the pipe, in this case with a speed of propagation of the pressure waves in the combustible gases of 580 m/s a fundamental frequency of  $580/0.8 = 725$  c/s could be expected. The good agreement indicates that in this case it was probably a question of organ pipe vibrations.

#### Pressure-volume diagrams

The mechanical engineer will generally be more accustomed to record cylinder pressures as a function of the piston displacement than as a function of the time. Since the displacement of the piston from its highest position is proportional to the volume increase  $v$  of the combustion chamber, and  $\int p \, dv$  is the work done by the gas or the recorded mechanical work, from the pressure-piston stroke diagram (pressure-volume diagram) the power delivered by the engine cylinder can be determined by planimetry. This was indeed originally the most important application of the indicator diagram.

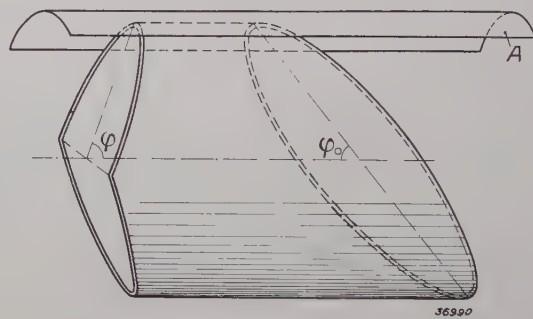


Fig. 8. Rotating cylinder condenser in the piston-stroke recorder.  $A$  fixed counter electrode.

In the article referred to<sup>1)</sup> the principle was briefly described of the arrangement whereby a horizontal deviation can be given to the fluorescent spot which is proportional to the displacement of the piston. The arrangement consists mainly of a cylinder cut off at the ends in a certain way, see fig. 8, which, together with a fixed counter electrode, forms a condenser. The cylinder is coupled with the crank-shaft, so that when the engine turns the capacity of the cylinder condenser varies periodically. The capacity variations are converted into voltage variations just as in the case of the pressure recorder, and the voltage variations are then fed to the hori-

zontal deflection plates of the cathode ray tube. We shall here go somewhat more deeply into the construction of the cylinder condenser.

Since the counter electrode is only relatively narrow, it may be said that the capacity of the cylinder condenser at every moment is proportional to the length of cylinder at the point which is exactly opposite the middle of the counter electrode. Since the capacity variation must be proportional to the piston displacement, the mode of variation in the length of the cylinder as a function of the angle is hereby prescribed. With the help of fig. 9

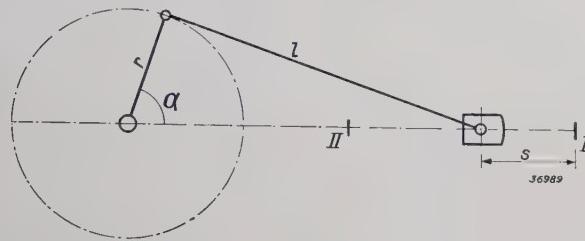


Fig. 9. Diagram showing the motion of the piston;  $r$  crank,  $l$  piston rod,  $I$  and  $II$  dead points. With infinitely long piston rod the piston displacement ( $s$ ) would be sinusoidal as a function of the angle  $\alpha$  of the crank. Due to the finite value of  $l$  a second harmonic enters the motion, whose amplitude depends upon the ratio  $\varepsilon = r/l$ .

for the displacement  $s$  of the piston from the highest position (dead point  $I$ , at which the volume of the cylinder is practically zero) the following formula is found:

$$s = r + l - r \cos \alpha - l \sqrt{1 - \varepsilon^2 \sin^2 \alpha} \dots \quad (1)$$

The ratio  $\varepsilon$  between the length of the crank ( $r$ ) and the piston rod ( $l$ ) generally lies between  $1/5$  and  $1/3.5$ . When the last term of (1) is developed in a series:

$$l \sqrt{1 - \varepsilon^2 \sin^2 \alpha} = l (1 - \frac{1}{2} \varepsilon^2 \sin^2 \alpha - \frac{1}{8} \varepsilon^4 \sin^4 \alpha - \dots),$$

then the term with  $\sin^4 \alpha$  is already at least 100 times as small as the preceding term, so that we may write in sufficient approximation:

$$s = r - r \cos \alpha + (l \varepsilon^2 \sin^2 \alpha)/2$$

$$\text{or } \frac{s}{r} = (1 - \cos \alpha) + \frac{\varepsilon}{4} (1 - \cos 2\alpha) \dots \quad (2)$$

The piston thus executes a practically sinusoidal motion upon which a weak second harmonic is superposed whose amplitude continues to depend upon the ratio of crank to piston rod of the engine in question. In fig. 10a the development of the cylinder condenser corresponding to equation (2) is drawn for the case where  $\varepsilon = 0.222$  ( $l = 4.5 r$ ). The cylinder is bounded at one end according to

the curve  $1 - \cos \alpha$  and at the other by  $(1 - \cos 2\alpha) \varepsilon/4$ . The length of the intermediate section of straight cylinder is in principle a matter of indifference, since it involves a constant capacity upon rotation, while we are only concerned with the variation in capacity.

The first-mentioned boundary  $(1 - \cos \alpha)$  can be realized in a very simple way by cutting off the cylinder by a flat surface having an arbitrary slope  $\varphi_0$  with respect to the cylinder axis. The boundary at the other end, according to  $(1 - \cos 2\alpha) \varepsilon/4$  is, however, more difficult to construct practically. For the sake of simplicity in manufacture therefore the approximation given in fig. 10b is introduced. The curve  $(1 - \cos 2\alpha) \varepsilon/4$  is replaced by  $(1 - |\cos \alpha|) \varepsilon/2$ , i.e. the cylinder is cut off by two flat planes whose position may be seen in fig. 8, while each plane makes an angle of  $\varphi$  with the cylinder axis, with  $\cot \varphi = (\varepsilon/4) \cdot \cot \varphi_0$ . It may easily be calculated that the greatest deviation between the curves of fig. 10a and b is equal to  $\varepsilon/8$ . For  $\varepsilon = 0.222$  this

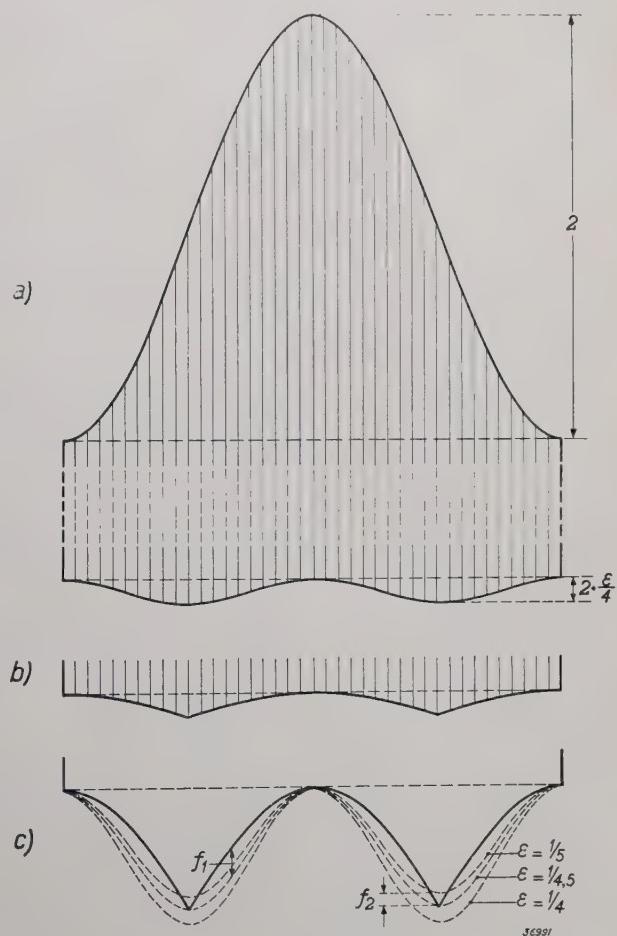


Fig. 10. Development of the condenser cylinder: a) theoretically desired form for a crank-piston rod ratio  $\varepsilon = 1/4.5$ ; b) approximation of the desired form, chosen because of its easy realization; c) on a scale 5 times as large: shape used (full line, like b) and theoretically desired shapes (broken lines) for different values of  $\varepsilon$ .

is a shift of the abscissa of 1.4 per cent of the total amplitude, an error which may be permitted without serious consequences.

If the same piston-stroke recorder is used for engines with a different ratio  $\varepsilon$  of crank to piston rod, larger errors may occur. This may be seen directly in fig. 10c where in addition to the curve for the recorder used (as in 10b) the form of the desired curve is drawn for several values of  $\varepsilon$ . In fig. 11 the maximum positive or negative deviation is plotted as a function of  $\varepsilon$ . If an error of 2.5 per cent is allowed, the piston-stroke recorder which is constructed with  $\cot \varphi = 1/4 \cdot 0.222 \cot \varphi_0$  is found to be still usable for engines with  $1/8 < \varepsilon < 1/3.6$ . Values of  $\varepsilon$  outside this range practically do not occur.

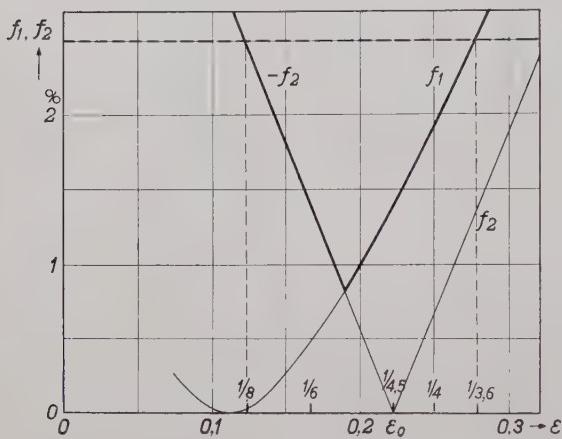


Fig. 11. Maximum difference  $f_1, f_2$  between the deflection obtained and that desired of the cathode ray, in per cent of the total piston stroke, as a function of the crank-piston rod ratio  $\varepsilon$  of the engine being tested. The values of  $\cot \varphi$  and  $\cot \varphi_0$  (see fig. 8) are here chosen in the ratio of 1 : 18. If a maximum positive or negative error of 2.5 per cent is allowed, the piston-stroke recorder so constructed can be used for all engines with  $1/8 < \varepsilon < 1/3.6$ , as the figure shows.

The above considerations actually hold only for the case where the counter electrode is infinitesimally narrow. When it has a finite width (angle  $\theta$ ), then the capacity at every moment is given by the average length of the cylinder in the effective sector of the surface of the cylinder. The effect of this is<sup>3)</sup> that higher harmonics in the variation of the cylinder length are weakened, the  $n^{\text{th}}$  harmonic by a factor  $(\sin \theta/2) (n\theta/2)$ . In order to obtain sufficient capacity  $\theta$  had practically to be made equal to  $10^\circ$ . The second harmonic hereby experiences only a relative weakening by a factor 0.995, so that the effect may be neglected.

In fig. 12 a normal pressure-volume diagram is reproduced, recorded with the help of the rotating cylinder condenser described. In order to obtain

such a diagram the counter electrode of the cylinder condenser must have a position such that the highest position of the piston corresponds to the smallest

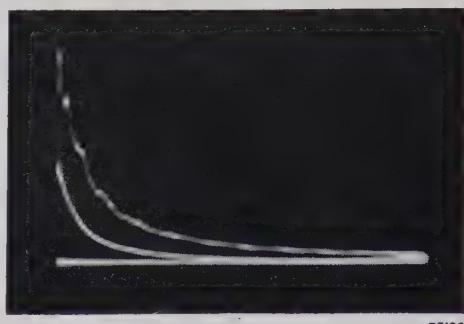


Fig. 12. Normal pressure-volume diagram recorded with the pressure indicator GM 3 154 and the piston-stroke recorder described. (Here again gas vibration in the indications channel are superposed.)

capacity (deflection of the cathode ray zero, or equal to a given initial deflection). From the diagram by planimetry, as already stated, the power delivered by the engine cylinder can be determined, and from this the mechanical efficiency can be calculated, for example with the help of the power measured at the crank-shaft.

Since in the neighbourhood of its highest position (and lowest position) the piston moves relatively slowly, the important processes of ignition and combustion, which take place about the moment when the piston is in the highest position, are compressed in the  $p$ - $v$  diagram into a short section of the abscissa. Peculiarities and possible deviations in the combustion cannot therefore be easily distinguished in the normal  $p$ - $v$  diagram. At the time when mechanical indicators were generally used the following device was employed to make up for this unpleasant lack. The motion in the direction of the abscissa was shifted  $90^\circ$  in phase with respect to the actual piston movement, so that the successive values of the pressure in the combustion chamber were not recorded above the corresponding volume values in the diagram, but were

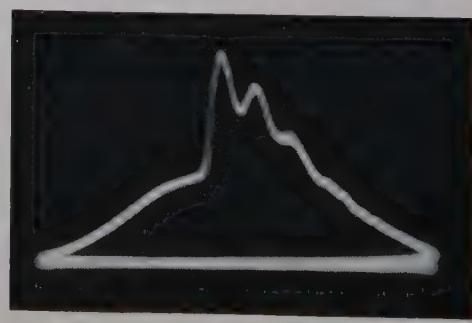


Fig. 13. "Shifted" pressure-volume diagram (same as fig. 12). The counter electrode of the cylinder condenser fig. 8 was here rotated  $90^\circ$  with respect to its normal position.

<sup>3)</sup> The effect is quite similar to that of the finite width of a scanning slit which was discussed in: J. F. Schouten, Synthetic sound, Philips techn. Rev. 4, 167, 1939 (see especially page 169).

shifted a quarter period. The combustion pressures thus lay in the middle part of the abscissa, where the motion is most rapid. The diagram obtained in this way, the so-called shifted *p-v* diagram, of which an example is given in fig. 13, gives a better idea of the actual combustion process than the normal *p-v* diagram, and could be obtained with the mechanical pressure indicator simply by moving a lever.

For the mechanical engineer who is accustomed to work with these shifted *p-v* diagrams, it was very simple in the case of the electrical indicator to obtain such diagrams. It was only necessary to rotate the counter electrode of the above-described piston-stroke recorder through the desired angle. The possibility of such a rotation had in any case to be provided for in connection with the testing of different cylinders of the same engine whose cranks always stand at different angles. The construction of the piston-stroke recorder shown in fig. 14 is such that the counter electrode can be turned with the hand and set at intervals of  $30^\circ$ . The most commonly occurring crank angles are multiples of  $30^\circ$ . At the same time a contact is also introduced on the axis of the rotating condenser which is closed once per revolution and which, as described above, serves for the synchronisation in the recording of pressure-time diagrams.

For routine testing of large engines, for instance of large Diesel installations, it is important to be able to test each cylinder separately. The indicating instrument is therefore provided with several connections which, via several cables, are connected to pressure recorders on the different

cylinders. When pressure time diagrams are being recorded, the diagrams of the different cylinders can be made to appear successively on the screen of the cathode ray tube simply by operating a switch. When, however, the piston-stroke base is being used, in addition to switching over to the corresponding pressure recorder, the counter electrode of the piston-stroke recorder must also be brought into the correct position for each cylinder.

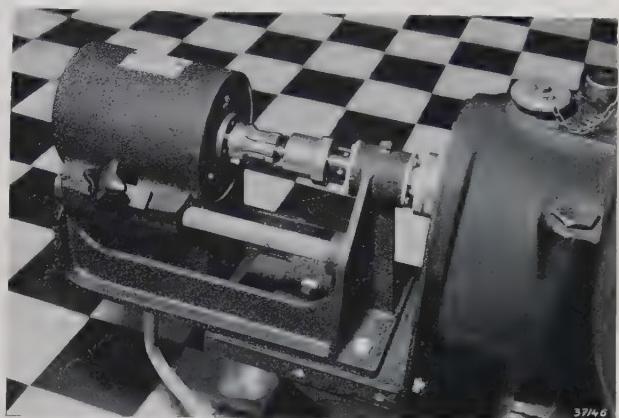


Fig. 15. Piston-stroke recorder (GM 4 300), larger model with operation at a distance, for large Diesel installations. The rotating condenser can be coupled with the crank-shaft by means of a sliding coupling arrangement which is here opened. It is so made, that it can be closed when the shaft is turning and the condenser cylinder automatically assumes the correct position with respect to the crank angles.

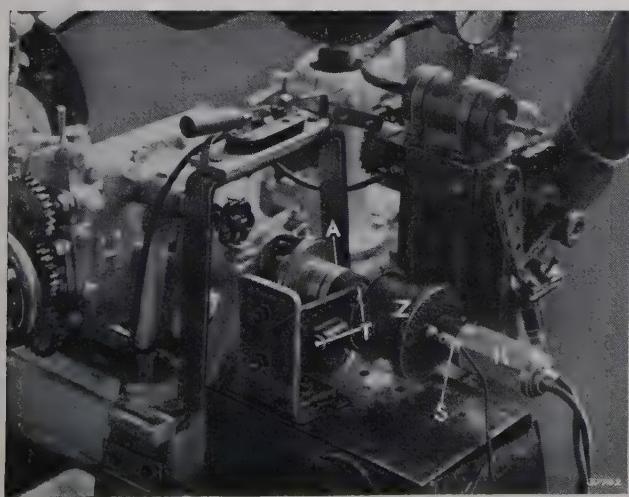


Fig. 14. Piston-stroke recorder Z (GM 4 301) coupled with the crank-shaft of a high-speed engine. *T* arrangement for fixing the counter electrode at definite angles, *S* connection for the synchronisation, *A* coupling with the engine shaft, *K* cable connection.

In order to simplify this manipulation a special piston-stroke recorder has been developed in which the counter electrode can be operated at a distance with the help of a small servo motor. Fig. 15 is a photograph of this recorder, while fig. 16 shows the construction of the indicator which is used in combination with it for large Diesel installations. The counter electrode is driven by the servo motor via a kind of Maltese cross which makes the electrode stop for a moment at intervals of  $30^\circ$ , so that the adjustment on the cylinders with different crank positions becomes much easier. A contact disc is attached to the counter electrode, which causes a series of signal lamps on the indicating instrument to light up, so that the position of the counter electrode can continually be checked. At the same time in this model of the piston-stroke recorder the axis of the rotating condenser has a contact disc by means of which the cathode ray can be periodically suppressed in such a way that the diagram on the fluorescent screen exhibits an interruption of the line every  $20^\circ$ . This provides easier orientation in the diagram.

In connection with the satisfactory functioning of the latter contact disc, the crank-shaft may not

make more than 800 r.p.m. With large engines, however, for which this model is chiefly intended, such a high speed of revolution practically never occurs. The simpler model shown in fig. 14 of the piston-stroke recorder can be applied up to much greater speeds, and therefore to high-speed engines such as racing engines.

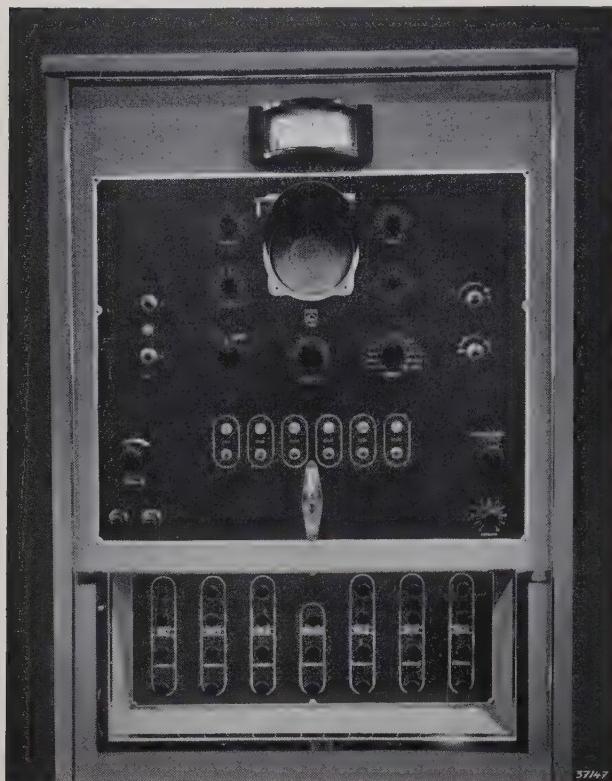


Fig. 16. Pressure indicator, model for large installations. In the centre of the upper half is the screen of the cathode ray tube. The middle of the seven sets of knobs visible below serve for the regulation of the compensation and the amplitude for the piston-stroke base (see the article referred to in footnote<sup>1)</sup>); the other six sets to the right and left serve for the corresponding regulations for six pressure recorders on different cylinders of the engine. Above these knobs may be seen a row of six times two signal lamps which light up when the counter electrode of the piston-stroke recorder for the corresponding cylinder is in the normal position or rotated 90°.

### The needle-stroke diagram

In addition to the diagrams discussed, the so-called needle-stroke diagram which records the motion of the fuel injection needle is also of importance to the constructor of Diesel engines. This needle is opened by the fuel pump operated by cams on a shaft coupled with the crank-shaft. The position and shape of the cams must be so chosen that the opening and closing of the valve needle takes place at the correct moment; furthermore the fuel supply line must be of the proper size so that the periodic pressure increase in the fuel oil will be propagated in the desired way from the pump to the needle.

In the article repeatedly referred to<sup>1)</sup> it was explained that the pressure recorder there described can in a simple way be adapted to the recording

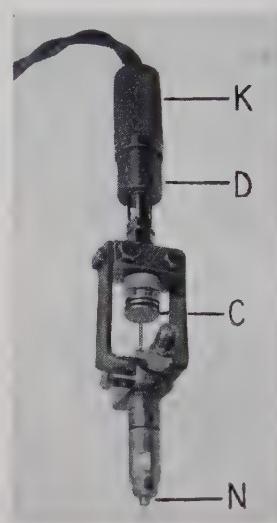


Fig. 17. Arrangement for the recording of a needle-stroke diagram. *N* fuel needle, *C* variable condenser of the pressure recorder *D* used as vibration recorder, *K* connecting piece for the cable.

of mechanical vibrations. The arrangement amounts to the setting up opposite the object to be investigated of a fixed, electrically insulated counter electrode, whose capacity with respect to earth varies due to the vibration. These capacity variations, in the same way as in the piston-stroke recorder and the normal pressure recorder, are converted into voltage variations which can be used for the deflection of the fluorescent spot of a cathode ray tube.

For recording the needle-stroke diagram a plate is now fastened above the needle, and above that the counter electrode of the vibration recorder is placed, see fig. 17. As horizontal deviation for the



Fig. 18. Needle-stroke diagram (1) and diagram of the pressure in the fuel supply line (2) recorded on the shifted piston-stroke base. By comparison with the corresponding shifted pressure-volume diagram (3) the phase of the pressure increase in the fuel supply line and of the opening of the needle can be accurately checked.

needle-stroke diagram the "shifted piston-stroke basis" is generally used, which was described above. If the shifted pressure-volume diagram itself is recorded simultaneously, it is easy to find out whether the injection takes place at the correct phase of the piston movement. The use of the shifted piston-stroke basis is here called for, since the injection takes place just in the neighbourhood of the dead point of the piston, where the normal piston-stroke basis most strongly compresses the diagram.

In fig. 18 such a needle-stroke diagram is shown, together with the corresponding shifted pressure-

volume diagram. The phase of the moment of injection can be accurately determined to within several crank degrees. In this figure, on the same basis, a diagram is also given which was recorded of the pressure variation in the fuel supply line at the pump. This liquid pressure can be measured with the ordinary pressure recorder used for gas pressures or with specially developed pressure recorders (with larger or smaller measuring range). In fig. 18 therefore use is made of all three possibilities of application of the indicator GM 3 154, namely for the recording of gas pressures, liquid pressures and mechanical vibrations.

# TEMPERATURE MEASUREMENTS WITH THE OPTICAL PYROMETER IN THE HARDENING DEPARTMENT

by J. RIEMENS.

536.52

A pyrometric method is described of measuring the temperature of a liquid bath between 850 and 1 450 °C with an accuracy of  $\pm 2^\circ$ . This arrangement is used in the factory for the measurement of the temperature of salt baths in the hardening department.

The hardening of steel is for the purpose of giving the metal that structure which possesses the desired properties. In earlier years when this treatment was carried out one could for the most part rely upon the experience of the foreman of the department. Modern metallurgy, however, has fundamentally altered the situation. New kinds of steel for special purposes have been developed, and these steels require a very precisely determined heat treatment in order to attain the desired properties. This is especially true of high speed tool steel which is much used for tools for metal working. In order to harden these tools they are introduced into a bath of fused salts and then cooled in a special way.

The temperature of the salt bath is of the greatest importance. In order to obtain reproducible results this temperature may not deviate more than about 5 degrees from the value at which the optimum result is obtained. This value generally lies between 850 and 1 450 °C.

Temperature measurements in the region mentioned can be carried out with sufficient accuracy not only with the help of thermoelements but also with the help of an optical pyrometer. For use in this temperature range only those ordinary thermoelements can be used which consist of platinum and platinum rhodium. In the practical use of these elements it has been found that the thermoelectric force gradually depreciates upon repeated heating above 1 300 °C, so that one is compelled to calibrate the element repeatedly and to replace it by a new element when the thermo electric force has diminished too much. This objection led to the adaptation of the optical method of measuring.

Optical pyrometry is based upon the fact that the brightness of a hot surface, for instance that of the salt bath, increases rapidly with the temperature. The brightness of the salt surface at a given temperature, however, also depends upon the composition of the salt, and small impurities may play an important part, so that the required measuring accuracy is difficult to obtain.

Greater accuracy is obtained by immersing in the salt a body whose brightness is accurately

known as a function of the temperature. An absolutely black body satisfies the requirement best. The black body can be realized by immersing in the bath a tube closed at the lower end. The part immersed must have a length at least four times the diameter of the tube. The radiation which emerges vertically out of the opening of the tube is then exactly the same as that of a black body of the temperature of the salt bath, within several tenths of a per cent. The temperature of the salt bath can therefore be determined directly by measuring the brightness of the opening of the tube.

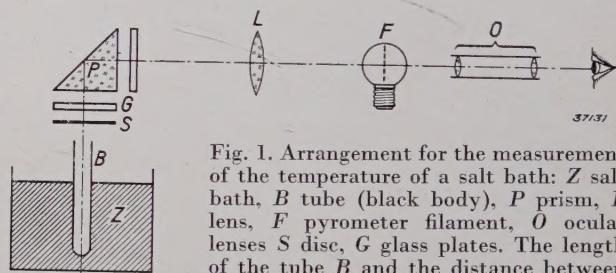


Fig. 1. Arrangement for the measurement of the temperature of a salt bath: Z salt bath, B tube (black body), P prism, L lens, F pyrometer filament, O ocular lenses S disc, G glass plates. The length of the tube B and the distance between B and the prism P are relatively much greater than shown in the figure.

In fig. 1 the arrangement is given. The bottom of the tube is focussed by means of the prism P and the lens L on a plane in which a glowing wire, the pyrometer filament, is situated. With the help of the ocular lenses O the pyrometer filament and the image of the bottom of the tube are examined together. If the current through the pyrometer filament is so regulated that the filament exhibits the same brightness as the tube bottom (and thus becomes invisible), the deviation of the ammeter which indicated the pyrometer current immediately furnishes a measure of the required temperature.

In order to obtain a correct result it is found that extreme care must be taken that salt vapours do not interfere with the pyrometry. By closing the tube this is sufficiently well ensured. Nevertheless in the long run the danger remains that small amounts of salt will be deposited on the optical parts of the pyrometer and thus change the calibration. In order to prevent this a metal disc S is introduced between the tube and the prism, and is only opened just before the measurement. For

all security the prism is also protected by two removable glass windows  $G$  which can be wiped clean from time to time. The prism therefore need never be cleaned, and cannot therefore be brought out of adjustment.

After some practice in the setting of the optical pyrometer an accuracy of measurement of about  $2^{\circ}\text{C}$  is attained at a temperature of from 1300 to  $1450^{\circ}\text{C}$ . An instrument of very good quality must, however, be used for measuring the pyrometer current. If a tungsten wire of 75 microns diameter is used as pyrometer filament, for example, it is found that the current must be able to be measured with a reproducibility of 2 tenths per cent.

Since the setting up of a precision instrument which satisfies such heavy requirements meets with difficulty in the rough surroundings of the hardening department, a kind of compensation connection

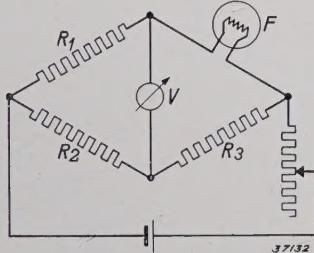


Fig. 2. Compensation connections for an accurate determination of the pyrometer current.  $R_1$ ,  $R_2$ ,  $R_3$  bridge resistances,  $F$  pyrometer filament.

is used for the measurement of the pyrometer current. The filament of the pyrometer is connected in one of the branches of a resistance bridge (see fig. 2). The resistance of the filament changes approximately proportionally with its temperature. The resistances of the other branches of the bridge are left unaltered; they are so chosen that at a temperature of  $850^{\circ}\text{C}$  the bridge is balanced, while at a temperature of  $1450^{\circ}\text{C}$  the full deviation of the meter  $V$  is obtained.

These connections have the advantage that the temperature range of practical importance occupies the whole scale of the meter, while with a direct measurement of the pyrometer current only about half of the scale of the ammeter can be used for this temperature range. The result is that the same accuracy of  $\pm 2^{\circ}\text{C}$  can be reached with a reproducibility which is 2.5 times as poor. With a good switchboard instrument one can measure accurately to within  $5^{\circ}$ , which is enough for practical purposes.

The constancy of the optical pyrometer is extremely great. Thanks to the relatively low filament temperature of  $1540^{\circ}\text{C}$  at the highest, the rate of evaporation of the tungsten wire is still very low, so that the properties of the wire during use remain practically unchanged. A semi-annual check of the instrument therefore gives sufficient guarantee that the permissible tolerance in the measuring result is not being exceeded.

## ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS GLOEILAMPENFABRIEKEN

**1506:** A. A. Kruithof: Townsend's ionization coefficients for neon, argon, krypton and xenon (*Physica* 7, 519-540, June 1940).

Townsend's ionization coefficient was determined for krypton and xenon as a function of  $E/p_0$ . Together with results already published for neon and argon (see 1106 and 1206), the measurements show that for  $E/p_0 < 40 \text{ V/cm} \times \text{mm}$  the ionization is strongest in neon. It is much less strong in argon and krypton and weakest in xenon. For high values of  $E/p_0$  the order is exactly reversed. Beginning with the fact that the average length of path as a function of the electron energy varies in about the same way for krypton and xenon as for argon, the ionization and probability of excitation could be approximately calculated for krypton and xenon from those of argon, with the help of the results of the measurements.

Furthermore the number of electrons was determined as a function of  $E/p_0$  which on an average, per positive ion formed in the gas, are freed from a copper cathode. The curves found make it possible to divide the freed electrons into two groups. One group contains the electrons liberated from the cathode by the collision of positive ions, the other group contains the photoelectrons freed by the very short-wave ultra violet radiation of the gas. For high values of  $E/p_0$  the first group is the largest, for low values the second.

**1507:** J. D. Fast: The action of gases on solid metals (*Chem. Wbl.* 37, 342-350, June 1940). (Original in the Dutch language)

In the corrosion of solid metals by gases a solid solution of the gas in the metal can be formed, whereby the gas atoms diffuse toward the interior of the metal, and a solid reaction product may be formed on the surface whereby the metal atoms diffuse through the layer formed in the direction of the gas phase. These phenomena are discussed in detail and illustrated with numerous examples, some from the literature and some from the author's own experiments. Part of the material

discussed in this article will be found in the August number of this periodical (5, 217, 1940: Metals as getters).

**1508\*:** F. A. Kröger: Luminescence in solids containing manganese (Dissertation, Amsterdam, July 1940).

In order to gain insight into the part played by manganese as an activator in phosphors, silicate and sulphide phosphors were investigated. In both, the manganese is present in solid solution in the crystal lattice, and is equivalent to the metal ions of the substance which serves as basic material. The light which excites the phosphors corresponds to their absorption spectrum and consists of discrete bands in the ultra violet and visible spectrum (characteristic of manganese), of a broad sharply defined band in the ultra violet resulting from the fundamental absorption of the built-in manganese compound, and in the third place of a broad band, at the long wave end bounded by the above-mentioned and at the short wave end with no observable boundary. This latter band is the fundamental absorption band of the basic material. Irradiation with light in the two last mentioned parts of the spectrum leads to fluorescence and phosphorescence accompanied by photoconductivity. Irradiation in the first part gives only fluorescence. The luminescence is characteristic of the built-in manganese ions and is ascribed to electron transitions within the manganese ion (transitions between the fundamental terms of the  $d^5$  configuration of the half-filled  $d$  shell).

The zone theory, which takes account of the possible energy levels in solid substances, is extended to include solid solutions, so that a usable model for the phosphors is obtained. With this it is shown that according to the characteristics of the emission a classification of the phosphors into two groups is possible. In the first group the emission process takes place within the excited centre, the emission is only secondarily dependent upon the environment. In the second group this environment, the basic material into which the activator is built, plays a part and the emission spectrum is strictly determined thereby. Manganese phosphors, according to the investigations referred to above, belong to the first group.

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\* An adequate number of reprints for the purpose of distribution is not available of those publications marked with an asterisk. Reprints of other publications may be obtained on application to the Natuurkundig Laboratorium, N.V. Philips' Gloeilampenfabrieken, Eindhoven (Holland), Kastanjelaan.